BRL-TR-3161

TECHNICAL REPORT BRL-TR-3161

BRL

AD-A231 021

DEGRADED STATES VULNERABILITY ANALYSIS: PHASE II

JOHN M. ABELL
MARK D. BURDESHAW
BRUCE A. RICKTER

OCTOBER 1990

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

NOTICES

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1990

3. REPORT TYPE AND DATES COVERED
Final, Sep 89 - Aug 90

4. TITLE AND SUBTITLE
Degraded States Vulnerability Analysis: Phase II

5. FUNDING NUMBERS
WU: DA31 6061

6. AUTHOR(S)
John M.Abell, Mark D. Burdeshaw, Bruce A. Rickter

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
BRL-TR-3161

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

In 1988, the Ballistic Research Laboratory (BRL) and the Army Materiel Systems Analysis Activity (AMSAA) began a joint program to develop improved metrics for use in vulnerability assessments, especially of ground combat vehicles. Traditional tank vulnerability metrics have made use of a mapping procedure called damage assessment lists (DALs). A DAL maps killed components and sets of components into degradation of combat utility (DCU). It has been known for a number of years that the use of DALs in the process of developing vulnerability measures of effectiveness is conceptually and mathematically problematic. Recent DAL work led to renewed focus on the problems associated with DALs, and to a proposal for their wholesale elimination from the process of vulnerability analysis, in favor of a methodology which yields the probabilities that a tank is in one or more degraded states.

The primary purpose of this paper is to exhibit inputs and results from Phase II of the implementation of the degraded states methodology which involved view average calculations. A secondary purpose is to compare the DAL-based metrics with degraded states metrics.

14. SUBJECT TERMS
Damage Assessment ~~List~~, Degraded States, Vulnerability, Tanks (Combat Vehicles)
~~View Average~~ ~~Methodology~~ Comparison ~~Aggregated~~

15. NUMBER OF PAGES
126

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

UNCLASSIFIED

INTENTIONALLY LEFT BLANK.

CONTENTS

LIST OF TABLES

INTENTIONALLY LEFT BLANK.

ACKNOWLEDGMENTS

A number of people and organizations provided us substantial help with generating view average calculations using this Degraded States methodology. Mr. Aivars Ozolins, of the Vulnerability Methodology Branch (VMB) of the Ballistic Research Laboratory (BRL), developed the view average approach for inclusion in the SQuASH model. He and Mrs. Cynthia Dively, also of the VMB, provided additional guidance on the operation of the SQuASH model and the inputs required to perform these calculations. Mr. Robert Wojciechowski, Mr. Ricky Grote and Mr. Dennis Bely of the Systems Assessment Branch of the BRL provided important insights into the operations of armored fighting vehicles. Mr. Charles Huenke of the Ground Systems Branch of the BRL provided guidance on the computer coding of view average calculations. Mrs. Lisa Roach and Mr. Scott Price, of the Integrated Battlefield Assessment Branch of the BRL, provided assistance in the execution and analysis of the view average calculations. Finally, Dr. Michael Starks, also of the IBAB, provided invaluable guidance and support throughout the analysis.

INTENTIONALLY LEFT BLANK.

I. Introduction

In 1988, the Ballistic Research Laboratory (BRL) and the Army Materiel Systems Analysis Activity (AMSAA) began a joint program to develop improved metrics for expressing the results of vulnerability assessments, especially of ground combat vehicles. Phase I was completed in May 1989;[1] this report documents the Phase II effort of the pilot program.

For Phase I, vulnerability assessments were compared for four different Damage Assessment Lists (DAL). In addition, the new Degraded States Vulnerability approach was implemented and the results were compared with the DAL results. Single shots involving a broad range of initial conditions (i.e. threat, range, azimuth, etc.) were used to generate the results for the comparisons.

In Phase II, view average vulnerability estimates were calculated for a representative set of initial conditions. An average estimate was calculated based on the estimates of each cell in a particular view or azimuth of fire. This average can be weighted uniformly or by the munition's delivery error relative to a given aimpoint. These estimates were calculated for both the Degraded States Vulnerability approach and the DAL approach.

The purpose of this report is to exhibit view average results for both the Degraded States and DAL metrics. We will show, as we did in Phase I, that the Degraded States metrics give a much more detailed vulnerability assessment of a vehicle. A secondary purpose is to illustrate typical output from the Degraded States metrics for view average vulnerability estimates.

II. Approach

The same methodology was used to calculate the view average vulnerability estimates for both the Degraded States and DAL metrics. This methodology was an adapted version of BRL's current Monte Carlo vulnerability code for point burst modeling,

---

1. J. M. Abell, L. K. Roach, M. W. Starks, "Degraded States Vulnerability Analysis", USA Ballistic Research Laboratory, TR-3010, June 1989, (Unclassified).

SQuASH (Stochastic Quantitative Analysis of System Hierarchies)[2 3], developed by the Vulnerability Methodology Branch (VMB) of BRL. For this analysis, only the portion of the code which calculates loss of combat functions was required. This portion of the code, called "SQuASHed", was used to generate loss of function values given a hit (LOF/H) for the DAL and probability of Degraded States given a hit (PDS/H) for the Degraded States approach. There are several published reports which describe the SQuASH model, so there will be no further discussion of the model in this report. However, the specific changes which were made for purposes of performing view average calculations will be addressed in sections III.3 and III.4.

The inputs to the "SQuASHed" model were provided by the VMB-BRL. The model requires two separate sets of inputs. The first set contains the component identification numbers from the computer generated target description of the AFV, a verbal description of these components and the DAL. The verbal description section, called the association table, acts as a liaison between the component identification table and the DAL. When a component is killed, "SQuASHed" uses this set of inputs to trace the component to the DAL.

The second set of inputs provides "SQuASHed" with a set of killed components. For each cell in the view (i.e. azimuth), a series of iterations (i.e. shotlines) are performed by the main SQuASH program: ten iterations per cell were made for this analysis. For each iteration, SQuASH generates a set of killed components and initial loss of function (LOF) values and writes both to a file called "Damage.States." The "Damage.States" file contains the initial loss of function values for Mobility (M), Firepower (F), Catastrophic (K) and Mobility or Firepower (M/F). These initial loss of function values are for hits to the ammunition and/or fuel compartments that do not result in a catastrophic event. When a catastrophic event does occur, these values are all set to 1.00 (i.e. total loss of function). The "SQuASHed" code uses this information to calculate M, F, K and M/F final loss of function values via the DAL or probability of degraded states via the Degraded States fault trees (see section III.2).

---

2. Aivars Ozolins, "Stochastic High-Resolution Vulnerability Simulation for Live-Fire Programs," *The Proceedings of Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA)*," held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988, (UNCLASSIFIED).

3. Paul H. Deitz, Aivars Ozolins, "Computer Simulations of the Abrams Live-Fire Field Testing," USA Ballistic Research Laboratory, MR-3755, May 1989, (UNCLASSIFIED).

A "Damage.States" file was generated for each threat, azimuth and range combination. There were two kinetic energy (KE) penetrators fired from six ranges (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 kilometers) at four azimuths (0, 30, 60 and 90 degrees). The elevation was zero degrees. In the "SQuASHed" code, the delivery errors (1, 2, 3, 5 and 10 foot sigmas) were varied for each threat, range and azimuth combination. Also, two exposures (fully exposed and hull defilade) were used in the model for each of the combinations. For each combination (threat, range, azimuth, delivery error and exposure), the "SQuASHed" code calculated both loss of functions values (M, F, K and M/F) using the DAL and probability of degraded state using the Degraded States approach.

III. Methodology

1. Damage Assessment List

The Damage Assessment List used in this analysis was obtained from the BRL-VMB. The list contains M, F, K and M/F loss of function values for each component(s) addressed. This DAL is shown in Table 1.

2. Degraded States

The Degraded States (DS) methodology describes vehicle loss of function in terms of six kill categories: mobility, firepower, acquisition, crew, communications and ammunition. The ammunition kill category was recently developed and added to the Degraded States approach; this is an improvement over the Phase I work. This approach represents a more robust set of metrics when compared to the traditional DAL metrics which provide only a single LOF value for both mobility and firepower. Each DS kill category contains a set of kill definitions which define degraded, but operational, states of the vehicle to include a "no damage" state. Also, in a particular kill category (except for crew), it is possible for two or more kill definitions to occur simultaneously; therefore, all possible combinations of kill definitions are considered in each kill category. Due to the inclusion of these combinations and the "no damage" state, the kill definitions are both exhaustive and mutually exclusive within a particular kill category. For any given damage to the vehicle, one kill definition from each of the six kill categories will be satisfied. The kill category combination represents the degraded state of the vehicle. The K-kill definition, K4, represents hits to the ammunition and fuel compartments and is included in the ammunition kill category in order to reduce the possible number of vehicle degraded states. The complete list of degraded state kill definitions for each kill category is contained in Table 2.

TABLE 1. Damage Assessment List for AFV

Event No.	M	F	K	M/F	Association Table No(s).	Component(s)
1	.30	.50	.00	.50	472 -473 -474 -475	commander only
1	.10	.50	.00	.50	473 -472 -474 -475	gunner only
1	.10	.30	.00	.30	474 -472 -473 -475	loader only
1	.30	.20	.00	.30	475 -472 -473 -474	driver only
1	.35	.75	.00	.75	472 474 -473 -475	commander & loader
1	.60	.75	.00	.75	472 475 -473 -474	commander & driver
1	.35	.80	.00	.80	472 473 -474 -475	commander & gunner
1	.20	.70	.00	.70	473 474 -472 -475	gunner & loader
1	.60	.75	.00	.75	474 475 -472 -473	loader & driver
1	.60	.75	.00	.75	473 475 -472 -474	gunner & driver
1	.95	.10	.00	.95	473 474 475 -472	commander sole survivor
1	.95	.90	.00	.95	472 474 475 -473	gunner sole survivor
1	.95	.95	.00	.95	472 473 475 -474	loader sole survivor
1	.90	.95	.00	.95	472 473 474 -475	driver sole survivor
1	1.00	1.00	.00	1.00	472 473 474 475	no survivors
2	1.00	.00	.00	1.00	481	engine
3	1.00	.00	.00	1.00	488	transmission
4	1.00	.00	.00	1.00	OR426OR427	final drive (any side or both)
5	1.00	.00	.00	1.00	OR503OR504OR430OR431	sprocket (wheel & hub)
6	.05	.00	.00	.05	478 -479	one sponson tank
6	.05	.00	.00	.05	479 -478	one sponson tank
6	.10	.00	.00	.10	478 479	both sponson tanks
7	.15	.00	.00	.15	476 -477	one bow fuel tank
7	.15	.00	.00	.15	477 -476	one bow fuel tank
7	.20	.00	.00	.20	476 477	both bow fuel tanks
8	1.00	.00	.00	1.00	480	fuel supply
9	.10	.00	.00	.10	553	intermediate roadwheel - 1
9	.20	.00	.00	.20	554	intermediate roadwheel - 2
9	.40	.00	.00	.40	555	intermediate roadwheel - 3
9	.50	.00	.00	.50	556	intermediate roadwheel - 4
9	.70	.00	.00	.70	557	intermediate roadwheel - 5
9	.85	.00	.00	.85	558	intermediate roadwheel - >5
10	1.00	.00	.00	1.00	OR507OR508OR552	track (any side & edge)
11	.25	.00	.00	.25	432 -433	right support roller - 1
11	.25	.00	.00	.25	433 -432	right support roller - 1
11	.50	.00	.00	.50	432 433	right support rollers - both
12	.25	.00	.00	.25	434 -435	left support roller - 1
12	.25	.00	.00	.25	435 -434	left support roller - 1
12	.50	.00	.00	.50	434 435	left support rollers - both
13	1.00	.00	.00	1.00	OR505OR506OR346OR351	idler (wheel & hub)
14	1.00	.00	.00	1.00	OR350OR355	track adjusting link
15	.65	.00	.00	.65	489 490	1st roadwheel (both sides)
15	.65	.00	.00	.65	489 -490 361	1st roadwheel (both sides)
15	.65	.00	.00	.65	490 -489 356	1st roadwheel (both sides)
15	.65	.00	.00	.65	-489 -490 356 361	1st roadwheel (both sides)
15	.50	.00	.00	.50	490 -489 -356	1st roadwheel (one side)
15	.50	.00	.00	.50	489 -490 356 -361	1st roadwheel (one side)

TABLE 1. Damage Assessment List for AFV (continued)

Event No.	M	F	K	M/F	Association Table No(s).	Component(s)
15	.50	.00	.00	.50	489 -490 -356 -361	1st roadwheel (one side)
15	.50	.00	.00	.50	-489 -490 356 -361	1st roadwheel (one side)
15	.50	.00	.00	.50	-489 -490 -356 361	1st roadwheel (one side)
16	.30	.00	.00	.30	501 -502	7th roadwheel (one side)
16	.30	.00	.00	.30	502 -501	7th roadwheel (one side)
16	.40	.00	.00	.40	501 502	7th roadwheel (both sides)
17	1.00	.00	.00	1.00	135	batteries
18	.65	.00	.00	.65	516	dc - shift
19	1.00	.00	.00	1.00	518	dc - steer
20	.65	.00	.00	.65	517	dc - throttle
21	.25	.00	.00	.25	519 -520	dc - service brake only
21	.00	.00	.00	.00	520 -519	dc - parking brake only
21	.40	.00	.00	.40	519 520	dc - all brake
22	.10	.00	.00	.10	565	driver's vis blk - 1
22	.25	.00	.00	.25	566	driver's vis blk - 2
22	.50	.00	.00	.50	567	driver's vis blk - all
23	.00	.20	.00	.20	154	cmdr's GPS extension
24	.01	.05	.00	.05	155	cmdr's weapon sight
25	.00	.00	.00	.00	559	cmdr's vis blk - 1
25	.00	.05	.00	.05	560	cmdr's vis blk - 2
25	.10	.05	.00	.10	561	cmdr's vis blk - 3
25	.15	.10	.00	.15	562	cmdr's vis blk - 4
25	.20	.20	.00	.20	563	cmdr's vis blk - 5
25	.50	.25	.00	.50	564	cmdr's vis blk - all
26	.00	.10	.00	.10	-537 536	GPS - daylight only
26	.00	.25	.00	.25	537 -536	GPS - TIS only
26	.00	.75	.00	.75	-153 537 536	GPS - both
26	.00	.97	.00	.97	153 536 537	GPS (both) & GAS
27	.00	.00	.00	.00	162	loader's sight
28	.00	.95	.00	.95	531	main gun
29	.00	.02	.00	.02	532	coaxial weapon
30	.00	.02	.00	.02	OR534OR535	cmdr's weapon
31	.00	.01	.00	.01	533	loader's weapon
32	.00	.01	.00	.01	247	coax ammo - ready only
33	.00	.01	.00	.01	256	loader's ammo - ready only
34	.00	.01	.00	.01	252	cmdr's ammo - ready only
35	.00	.24	.00	.24	539 -540 -541	fc - MHP (normal)
35	.00	.24	.00	.24	539 -540 541	fc - MHP (normal & emergency)
35	.00	.35	.00	.35	539 540 -541 -542	fc - MHP & AHP (normal)
35	.00	.35	.00	.35	539 540 -541 542	fc - MHP (norm) & AHP (norm & emerg)
35	.00	.35	.00	.35	539 540 541 -542	fc - MHP (normal & emergency) & AHP (normal)
35	.00	.80	.00	.80	-543 539 540 541 542	fc - all power
35	.00	.97	.00	.97	543 539 540 541 542	fc - all
36	.00	.40	.00	.40	538	target range
37	.30	.30	.00	.30	OR546OR547OR549	intercoms
38	.30	.00	.00	.30	548	driver's intercom
39	.00	.20	.00	.20	OR550OR551	external communications

Table 2. List of AFV Kill Definitions

Mobility Kill Category

MO--> No mobility damage

M1--> Reduced speed (slight)

M2--> Reduced speed (significant)

M3--> Total immobilization

Firepower Kill Category

FO--> No firepower damage

F1--> Loss of main armament

F2--> Unable to fire on the move

F3--> Increased time to fire

F4--> Reduced delivery accuracy

F5--> Loss of secondary armament

F6--> F2 and F3

F7--> F2 and F4

F8--> F3 and F4

F9--> F2 and F3 and F4

F10--> F2 and F5

F11--> F3 and F5

F12--> F4 and F5

F13--> F2 and F3 and F4 and F5

F14--> F2 and F3 and F5

F15--> F2 and F4 and F5

F16--> F3 and F4 and F5

F17--> F1 and F5 (total loss of firepower)

Acquisition Kill Catogory

AO--> No acquisition damage

A1--> Reduced acquisition capability

A2--> Unable to acquire while moving

A3--> A1 and A2

Crew Kill Category

CO--> 0 crew casualties

C1--> 1 crew casualties

C2--> 2 crew casualties

C3--> 3 crew casualties

C4--> 4 crew casualties

Communications Kill Category

XO--> No communication damage

X1--> No internal communications

X2--> No external communications >300 feet

X3--> No external communications

X4--> X1 and X2

X5--> X1 and X3

Ammo Kill Category

KO--> No ammo lost

K1--> Bustle ammo lost

K2--> Hull ammo lost

K3--> K1 and K2

K4--> K Kill

<u>Combinations</u>

M(0-3)		F(0-17)		A(0-3)		C(0-4)		X(0-5)		K(0-4)		
4	X	18	X	4	X	5	X	6	X	5	=	43,200 states

For shorthand purposes, the alphanumeric name assigned to each of the kill definitions in Table 2 will be used throughout the remainder of this report. For example, state M3 represents the kill definition for total immobilization of the vehicle. The total number of possible combinations of vehicle degraded states is shown at the bottom of Table 2.

Mathematical fault trees were developed to represent the degraded state kill definitions in each kill category. These fault trees consisted of a list of critical vehicle components that, if killed, would result in that particular kill definition being satisfied. For a particular kill category, a kill definition is achieved when no uninterrupted path can be traced from top to bottom in the fault tree. The fault tree path configurations can be described as having components arranged in series or in parallel or as some combination of the two. If listed in series, the loss of any component would cause an interruption in the path whereas those components listed in parallel must all be killed to interrupt the path. The components listed in the fault trees can represent either a single critical component or a system of critical components. The systems of components were developed into fault tree configurations in the criticality analysis performed by the BRL-VMB.[4] The criticality analysis also provided a list of approximately five hundred critical components from which the degraded state fault trees were developed. After the initial strawman trees were developed, they were reviewed by the appropriate personnel at BRL, AMSAA, the US Army Ordnance Center and School (USAOC&S) and the US Army Armor Center and School (USAAC&S). Recommended changes to the trees from these groups were incorporated in the final fault tree configurations for each kill definition in all six kill categories. The final fault trees are shown in Appendix A.

The fault trees were incorporated into the "SQuASHed" code using the BRL-VMB's Interactive Criticality Evaluator (ICE) program. The ICE program translated the fault trees into mathematical FORTRAN statements called SHOTPK equations. These mathematical expressions depict the appropriate Boolean operation for each component (i.e. series or parallel). Once the set of killed components has been determined (via the "Damage.States" file), the SHOTPK equations use them to determine which fault trees have been cut. Since cutting a fault tree equates to achieving that kill definition, the SHOTPK equations determine which kill definition is satisfied for each of the six kill categories. The combination of one kill definition from each of the six kill categories represents the degraded state for the vehicle.

---

4. Joseph J. Ploskonka, Theodore M. Muehl, Cynthia J. Dively, "Criticality Analysis of the M1A1 Tank," US Army Ballistic Research Laboratory, BRL-MR-3671, June 1988, (UNCLASSIFIED).

3. View Average Required Code Changes

As stated earlier, the purpose of this report is to compare view average results for both the Degraded States and the DAL approaches. To produce view average results, several changes had to be made to the "SQuASHed" program used in the Phase I analysis. As part of the SQuASH program processing (performed by the VMB), a grid system must be overlaid on the target in order to perform the cell by cell analysis; a 4 inch grid cell system was used for this analysis. The results of the cell by cell vulnerability analysis are stored in the "Damage.States" file; recall, this file contains the set of killed components for each iteration (i.e. shotline) of each grid cell. Since there were ten Monte Carlo iterations per grid cell and 749, 1400, 1630 and 1503 cells for 0 , 30 , 60 and 90 azimuth, respectively, VMB provided the data in packed binary form to reduce the required computer storage. To read this data as input for "SQuASHed," an input routine was developed to unpack the packed binary input file, assign the values to the appropriate variables, and print the header information to confirm that the file was read correctly. The data were provided for all cells which covered any part of the vehicle.

After the "Damage.States" file was read, "SQuASHed" calculated the vulnerability estimates via the DS fault trees or the DAL for each iteration. The next change to the program involved the handling of the ten iterations per cell. For the DAL case, the output for each shotline was the four LOF values, M, F, K, and M/F, thus, generating ten sets of LOF values for each grid cell. The LOF values for each cell were calculated by taking the average of the ten values in that cell. Then, averaging over the number of cells in that view, an unweighted view average LOF value was computed for these four kill criteria.

For the Degraded States case, the process was more complex. The Degraded States procedure produced a single vehicle degraded state per iteration; therefore, each cell could have contained up to ten different vehicle degraded states. For example, Table 3 shows the different vehicle degraded states that could be obtained from a single cell (see Table 2 for Degraded States kill definitions).

TABLE 3. Example Degraded States for One Cell

ITERATION	STATE					
	M	F	A	C	X	K
1	0	1	3	1	0	0
2	0	0	0	0	0	0
3	0	1	3	1	0	0
4	0	1	3	1	0	0
5	0	1	3	1	5	0
6	0	1	3	1	0	0
7	0	1	3	1	0	0
8	0	1	3	1	0	0
9	0	1	3	1	5	0
10	0	1	3	1	0	0

Since a different vehicle degraded state could occur for each iteration, "SQuASHed" kept track of each different vehicle degraded state and its probability for each cell. For example, given the set of vehicle degraded states in Table 3 for a certain cell, Table 4 shows how the data would be consolidated and sorted.

TABLE 4. Example DS Cell Output

STATE						PROBABILITY	CUMULATIVE
M	F	A	C	X	K		
0	1	3	1	0	0	0.7	0.7
0	1	3	1	5	0	0.2	0.9
0	0	0	0	0	0	0.1	1.0

After the degraded states of the vehicle were calculated for each cell, a consolidating/sorting algorithm was used to combine like degraded states. This routine summed the probabilities of identical vehicle degraded states and sorted them in descending order by their probabilities. The DS average was taken uniformly, as was the LOF average.

Up to this point in the calculations it has been implicitly assumed that each cell has the same probability of being hit. This probability distribution, relative to the aimpoint, is unrealistic for assessing the vulnerability of vehicles given the delivery error of the threat. A more realistic approach is to assume a normal probability distribution about the aimpoint, weighting the probability of hitting the target more heavily about the aimpoint and less for cells farther from the aimpoint; therefore, a normal distribution was assumed on the horizontal and vertical axes of the vehicle with the mean on the aimpoint and the standard deviation representing the delivery error of the threat (i.e. dispersion value). Dispersion values used were 1, 2, 3, 5, and 10 feet.

The changes to the "SQuASHed" program to implement the weighted view average procedures involved creating a weighting algorithm to calculate the probability of hitting a certain cell on the target given an aimpoint and dispersion value. The aimpoints used for the four azimuths and two exposures were center of presented area. Once the processing for each cell was completed, the values in the cell, both DAL LOF values and DS probabilities, were weighted by the probability of hitting that cell. The consolidating/sorting algorithm described above was used to calculate the weighted view average results.

4. Outputs

For this analysis, the "SQuASHed" program provided two forms of output. The first form of results was the DAL and Degraded States individual cell results, unweighted and weighted. An example of a single cell result for Degraded States was displayed in Table 4. The second form of results was the vehicle degraded states/DAL metrics and their associated probabilities/LOF values given a hit to the vehicle in descending order. An example of the DS form of output is shown in Table 5.

TABLE 5. Example of Degraded States Output

STATES						PROBABILITY	CUMULATIVE
M	F	A	C	X	K		
3	9	3	1	5	0	0.108	0.108
0	0	0	0	0	0	0.107	0.215
3	17	3	4	5	4	0.090	0.305
3	1	3	1	5	0	0.084	0.389
3	1	3	1	0	0	0.062	0.451
3	9	3	0	5	0	0.038	0.489
0	1	3	1	0	0	0.037	0.526
3	0	0	0	0	0	0.036	0.562
0	1	0	0	0	0	0.036	0.598
3	1	3	2	5	0	0.034	0.632
3	9	3	1	0	0	0.033	0.665
0	1	3	0	0	0	0.031	0.696
0	1	3	2	0	0	0.028	0.724
3	1	3	2	0	0	0.028	0.752
3	1	3	0	5	0	0.017	0.769
0	1	3	3	5	0	0.014	0.783
3	1	3	3	5	0	0.014	0.797
3	8	3	1	0	0	0.013	0.810
3	9	3	2	5	0	0.013	0.823
0	1	3	3	0	0	0.013	0.836
3	1	3	0	0	0	0.011	0.847
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
0	1	2	0	5	0	0.001	0.992
2	1	3	0	0	2	0.001	0.993
1	0	1	1	0	0	0.001	0.994
2	1	3	1	5	1	0.001	0.995
0	1	1	0	0	1	0.001	0.996
3	0	1	0	0	0	0.001	0.997
2	1	3	2	5	1	0.001	0.998
2	9	3	3	0	0	0.001	0.999
3	8	3	0	5	0	0.001	1.000

Finally, an output algorithm was developed to consolidate the DS and DAL output according to initial conditions (threat, exposure, azimuth, range, and dispersion). An example of the DS output is shown in Table 6. The first column contains the vehicle degraded states; the next four columns contain the probabilities for the four azimuths (views); the sixth column contains the uniform average probability over the four views; and the final column contains the cardioid average probability.

TABLE 6. Example of DS Formatted Output

Exposure: Fully exposed
Threat: PI
Range: 1000 meters
Dispersion: 2 feet

Damage						Views				Uniform	Cardioid
(M	F	A	C	X	K)	0	30	60	90	Average	Average
3	9	3	1	5	0	0.108	0.018	0.034	0.008	0.037	0.039
0	0	0	0	0	0	0.107	0.077	0.044	0.123	0.088	0.089
3	17	3	4	5	4	0.090	0.090	0.045	0.028	0.063	0.062
3	1	3	1	5	0	0.084	0.095	0.095	0.027	0.075	0.073
3	1	3	1	0	0	0.062	0.023	0.010	0.009	0.026	0.026
3	9	3	0	5	0	0.038	0.048	0.030	0.026	0.036	0.035
0	1	3	1	0	0	0.037	0.016	0.014	0.010	0.019	0.020
3	0	0	0	0	0	0.036	0.066	0.020	0.017	0.035	0.033
0	1	0	0	0	0	0.036	0.012	0.005	0.002	0.014	0.014
3	1	3	2	5	0	0.034	0.058	0.045	0.010	0.037	0.035
3	9	3	1	0	0	0.033	0.006	0.005	0.006	0.012	0.013
0	1	3	0	0	0	0.031	0.023	0.017	0.009	0.020	0.020
0	1	3	2	0	0	0.028	0.013	0.004	0.004	0.012	0.013
3	1	3	2	0	0	0.028	0.017	0.007	0.000	0.017	0.013
3	1	3	0	5	0	0.017	0.048	0.032	0.016	0.028	0.027
0	1	3	3	5	0	0.014	0.004	0.002	0.011	0.008	0.008
3	1	3	3	5	0	0.014	0.009	0.004	0.002	0.007	0.007
3	8	3	1	0	0	0.013	0.003	0.006	0.001	0.006	0.006
3	9	3	2	5	0	0.013	0.003	0.001	0.000	0.006	0.004
0	1	3	3	0	0	0.013	0.010	0.001	0.001	0.006	0.006
3	1	3	0	0	0	0.011	0.016	0.017	0.014	0.014	0.014
3	9	3	0	0	0	0.009	0.038	0.042	0.047	0.034	0.034
0	1	3	0	5	0	0.008	0.017	0.018	0.008	0.013	0.012
0	1	3	2	5	0	0.007	0.006	0.008	0.009	0.007	0.007
0	1	3	1	5	0	0.006	0.012	0.015	0.008	0.010	0.010

.
.
.

IV. Results

The results of this analysis were voluminous due to the number of initial condition combinations and the nature of the degraded states output; therefore, when appropriate, only examples or portions of the results will be presented. All DAL or Degraded States results (except the individual cell plots) are LOF or probability of degraded states (PDS), respectively, given a hit.

1. Probability Distribution of Degraded States

A probability distribution of vehicle degraded states was generated for each set of initial conditions (all possible combinations of threat, range, azimuth, exposure and dispersion). The distribution consisted of a set of vehicle degraded states listed in descending order according to their probabilities, to include their associated cumulative probabilities. The vehicle degraded states are combinations of the six kill categories and represent the form of output provided to AMSAA for input to their force-level model, Degraded States Weapons Analysis Research Simulation (DSWARS). In all the runs, the number of vehicle degraded states realized was considerably less (no more than approximately 200) than the 43,200 possible combinations. Table 5 provided an example of a probability distribution of vehicle degraded states. For force-level comparisons, a set of traditional DAL metrics (M, F, K & M/F) for each set of initial conditions was also provided to AMSAA. In addition to the probability of vehicle degraded states and the final loss of function values for each view, uniform and Cardioid averages were calculated over the four views or azimuths (0, 30, 60 and 90 degrees). For the Cardioid average, the weighting factors for 120, 150 and 180 degrees were added to the factor at 90 degrees azimuth.

A numerical comparison of the two approaches is not possible with this form of output. The damage to a particular kill category is accounted for in several vehicle degraded states and probabilities whereas the DAL provides a single LOF value. Later in this report, these DS probabilities will be aggregated so that numerical comparisons can be made with the DAL LOF values.

The probability distribution of these vehicle degraded states provides a much fuller description of the damage to the vehicle than does the traditional DAL metrics. The distribution describes, in detail, the frequency and degree of the damage to each of the six kill categories. The higher resolution of the Degraded States output provides information which is aggregated away in the DAL process. For example, using the Degraded States distribution, the frequency of inflicting one, two, three or four crew casualties can be determined. Also, the probability of a particular kill definition in one kill category occurring simultaneously with a particular kill definition in another kill category can be calculated. For example, when making the numerical comparisons (discussed later) to the DAL metrics, it was of interest to know how probable it was to have no firepower damage, yet still have crew and/or communications damage.

The remainder of the results involve comparisons between the two approaches. Since the DS full probability distribution cannot be compared to the DAL LOF values, each individual kill definition and its associated probability were extracted from this distribution (see Appendix D). There were two reasons for displaying the DS output in this manner. First, the kill definition probabilities clearly illustrate the detailed data on vehicle damage available with the full distribution of degraded states. Second, it allows for numerical comparisons in magnitude between the two methodologies. In the following sets of DS results, the DS probabilities were aggregated in one of two ways to allow for comparison with the DAL LOF values. Either, the kill definition probabilities were summed within each of the six kill categories, referred to as "hardware only" aggregations, or the kill category probabilities were aggregated in order to include those components which are lumped into the DAL M, F and M/F LOF values. Table 7 identifies these two DS aggregations.

TABLE 7. Aggregated DS Probabilities

Hardware Only

P(M) = P(M1) + P(M2) + P(M3)
P(F) = P(F1) + P(F2) + ... + P(F17)
P(A) = P(A1) + P(A2) + P(A3)
P(C) = P(C1) + P(C2) + P(C3) + P(C4)
P(X) = P(X1) + P(X2) + P(X3) + P(X4) + P(X5)
P(K) = P(K1) + P(K2) + P(K3)
K-Kill = P(K4)
M or F = P(M) or P(F)

Aggregated

M = P(M) or P(C) or P(X) or P(K)
F = P(F) or P(A) or P(C) or P(X) or P(K)
K-Kill = P(K4)
M or F = P(M) or P(F) or P(A) or P(C) or P(X) or P(K)

2. Individual Cell Plots

The highest resolution form of the "SQuASHed" output was used to generate individual cell plots for both the DAL LOFs (M, F, K, M/F) and DS probabilities. This output contained the PDS or DAL LOFs for each of the ten iterations in each four inch cell. The number of cells output depended on the azimuth of fire. The PDS/LOF values used for these individual cell plots were not weighted.

The cell-by-cell output was reformatted so that the BRL program, "cell-Fb", could be used to generate the individual cell probability plots. For the DAL, the average (over the ten iterations) LOF values for M, F, K and M/F were read for each cell. For the Degraded States, the vehicle degraded states and their

probabilities were read, but certain calculations had to be performed before the plots could be made. The probability of a particular kill definition was calculated by summing the number of times that kill definition was satisfied in a given cell and dividing by the number of iterations. For a Degraded States kill category, the probabilities of all the kill definitions in that kill category, except the "no damage" state, were summed; therefore, the M or F Degraded States probability represents the union of the two kill category probabilities. It is important to note here that the Degraded States cell plots do not contain the damage to other kill categories, such as communications, crew and acquisition, which are aggregated into the DAL LOF cell plots. The Degraded States K-kill value was the probability of kill definition K4 for each cell. Finally, the probabilities or LOF values were formatted for the "cell-Fb" program which generated the plots. The plots are color coded on a scale of 0 (white) to 1 (red).

Individual cell plots were generated for Degraded States kill definitions and kill categories, and DAL LOF values. All of the plots are for the larger KE penetrator (P1) at a range of 1 kilometer for a fully exposed target. These plots are contained in Appendix B of this report.

a. **Degraded States Kill Definitions.** The individual kill definition cell plots illustrate the amount of detail that is available from these new, improved metrics. The probability of a kill definition is depicted in each cell by color. The following kill definitions were plotted:

TABLE 8. Kill Definitions Plotted

M1 - Reduced speed, slight	F1 - Loss of main armament
M2 - Reduced speed, significant	F8 - Increased time to fire & Reduced delivery accuracy
M3 - Total immobilization	F9 - Unable to fire on the move & Increased time to fire & Reduced delivery accuracy
C1 - One crew casualty	F17 - Total loss of firepower
C2 - Two crew casualties	
C3 - Three crew casualties	
C4 - Four crew casualties	

In the mobility kill category, Figure B-1 shows that when kill definition M1 is satisfied, components in the lower portions of the vehicle are killed. In a couple of the higher probability cells, roadwheels were the most frequently killed components. The kill definition M2 plot, also in Figure B-1, shows a concentration in the driver's area. Analysis of various cells proved that the loss of driver's controls is the main reason for satisfying this kill definition. Even the cells in the upper portion of the vehicle reflect killed cables which ultimately eliminate some driver's control. A large concentration of high probability cells exists in the lower half of the vehicle for kill definition M3 as shown in Figure B-2. The loss of systems such as engine, transmission, track and fuel control was the cause.

In the firepower kill category, kill definitions F1, F17, F8 and F9 were plotted. As seen in Figure B-3, kill definition F1 showed a high probability concentration near the center of the vehicle which represented losing the main gun, all gunner's sights and/or all ability to traverse or elevate the turret. The majority of the occurrences of kill definition F17 are due to catastrophic events; therefore, Figure B-3 mainly shows hits to the fuel and ammunition compartments. As seen in Table 8, kill definition F9 included the vehicle's inability to fire on the move and kill definition F8 did not. This equates to losing the main hydraulic power (traverse or elevation), which will achieve kill definition F8, or losing the main and auxiliary hydraulic power (traverse or elevation) which equates to achieving kill definition F9. As Figure B-4 shows, the probability of losing the main and not the auxiliary power (i.e. kill definition F8) was small.

In the crew kill category, Figures B-5 and B-6 show where and how frequently, one or two and three or four crew casualties, respectively, occurred. The location helps determine which particular crew member(s) was killed. Loss of four crew members is due mainly to catastrophic events; therefore, the C4 plot in Figure B-6 depicted hits to the fuel and ammunition compartments. Figure B-7, the plot for all crew casualties, shows the summation of the probabilities of kill definitions C1 through C4 in each cell.

This resolution of vehicle damage can not be obtained with DAL LOF plots. For this reason, there was no comparison to the DAL at this level. These individual cell plots show the location and frequency of kill definitions and allow particular component losses to be associated with specific loss of capability.

b. **Comparison of Degraded States and DAL.** To compare the two methodologies using cell plots, the kill definition probabilities were summed over the mobility and firepower kill categories, respectively. This comparison was not completely appropriate for two reasons. First, the Degraded States kill category probabilities did not include components from other kill categories such as acquisition, crew and communications whereas the DAL plots represented LOF values due to all killed components. The second reason was that, numerically, probabilities were being compared to LOF values.

The comparisons revealed similar plots for both mobility and firepower as seen in Figures B-8 and B-9, respectively. Recall, no conclusions can be drawn numerically since the values (represented by colors) for each cell had different meanings for the two methodologies. Comparing the location of the colored areas indicates that both methodologies considered the same group of components as critical to the function of the vehicle in terms of mobility and firepower. Also, those colored areas that were not in common revealed components which were treated differently by the two methodologies. For example, when killing only the batteries, the DAL reported total loss of function in terms of mobility whereas the degraded states approach, which follows the VMB criticality analysis, reports no mobility damage. Also, the loss of sponson and/or bow fuel tanks gave M LOF

values, but were not included in the Degraded States fault trees.

3. Excursions

For both methodologies, a set of excursions was performed to determine the sensitivity of the results to changes in the initial conditions. The intent of these excursions was to show that no unexpected trends occurred in the results. This was accomplished by comparing the results across the various parameters which represented the initial conditions (range, dispersion, threat, exposure and azimuth). For the DAL, the kill criterion compared was the M/F LOF value. For the DS methodology, the probability of some mobility kill definition (other than M0) or some firepower kill definition (other than F0) was used. This probability was calculated from the probability distribution of vehicle degraded states. The results of sensitivity comparisons are displayed in bar charts contained in Appendix C.

a. **Range Sensitivities.** There were two range sensitivity excursions performed. One kept the delivery error constant across the six ranges and the other varied the error according to the range. The error selected for each range was based on a "rule of thumb"[1] as shown in Table 9.

TABLE 9. Range/Delivery Error Pairings

Range	Associated Delivery Error (sigma)
0.5 km	1 foot
1 km	2 foot
1.5 km	3 foot
2.0 km	5 foot
2.5 km	5 foot
3.0 km	10 foot

The comparisons were performed for both threats and exposures at zero and ninety degrees azimuth.

Figures C-1 through C-4 display the results of the excursions where the dispersion was held constant. As these figures show, the results decrease as the range increases (for both bullets and exposures) since residual penetration decreases. The same was true when the dispersion values were varied, as one can see from Figures C-5 through C-8. However, there was one exception; in Figure C-7, the vehicle was fully exposed and the smaller KE penetrator's results slightly increase as the range increases at zero degrees azimuth. In most armored fighting

1. Private conversation with Cynthia Dively of the VMB.

vehicles, the front, center portion of the vehicle is the most heavily armored area; therefore, the smaller threat does not penetrate. In this excursion, the dispersion values increase with range, thus presenting target area that is not as heavily armored. In all of the range sensitivities, both methodologies show similar trends for this kill criterion.

b. **Dispersion Sensitivities.** Excursions were performed to show the sensitivity of the results to dispersion values. For both threats and exposures, the results were compared at two different ranges (1 and 3 km) and azimuths (0 and 90 degrees) for the five dispersion values (1, 2, 3, 5 and 10 foot sigmas).

The results, contained in Figures C-9 through C-16, decrease when the dispersion values increase in all cases except one. Since the aimpoint is at the center of the target, the more dispersed the threat is from the aimpoint, the less damage is inflicted. The exception is with the smaller KE penetrator for a fully exposed vehicle at zero degrees azimuth. Inspection of Figures C-11 and C-15 illustrates the opposite trend for both ranges (1 and 3 km). The explanation given in the range sensitivity excursions, where dispersion values were varied with range, also holds true for these cases. Both trends are consistent with results from previous studies involving this vehicle. The trends for both methodologies are similar for all dispersion excursions.

c. **Threat Sensitivities.** The next set of excursions illustrates the sensitivity of the results to the threat employed. The results of threats P1 and P2 were compared for two range/dispersion combinations, both exposures and all four azimuths. The range/dispersion combinations were 1 and 3 kilometers with two and ten foot sigmas, respectively. In all cases, as shown in Figures C-17 through C-20, the damage inflicted by threat P1 was more severe, as expected. The trends between the two threats' results are similar for both methodologies for this kill criterion.

d. **Exposure Sensitivities.** Next, the sensitivity of the results to exposure (either fully or hull defilade) was investigated. The same set of initial conditions for the threat excursions was used for these comparisons. Figures C-21 through C-24 show, as expected, that the larger presented area for the fully exposed vehicle results in a higher PDS/LOF in all of the comparisons. Again, the trends for each azimuth are similar for both methodologies with respect to this kill criterion.

e. **Azimuth Sensitivities.** The final set of sensitivity excursions was performed on the azimuth or view. Using the same range/dispersion combinations, the results for all threat/exposure combinations were compared across the four azimuths (0, 30, 60 and 90 degrees). In general, the lowest PDS/LOF values are observed at 0 degrees azimuth and the highest at 60 or 90 degrees azimuth. This is due to the armor protection afforded and the presented area for each azimuth. These results are contained in Figures C-25 through C-28. The trends across the azimuths are similar for both methodologies with respect to this kill criterion.

4. Degraded States vs. DAL Comparisons

Ultimately, the goal of this analysis was to make comparisons between the two methodologies. In addition, AMSAA is using the BRL data for a comparison of DAL and DS results in an adapted version of their force-level model, GROUNDWARS. GROUNDWARS, which uses the traditional DAL metrics, was adapted to also accept the DS metrics. The new model, DSWARS, was run using the BRL results for both methodologies and the outputs compared. AMSAA's analysis was completed in the third quarter FY90.[5]

There were two numerical comparisons of the Degraded States probabilities and the DAL LOF values. Both comparisons were made at the 1 kilometer range with a 2 foot dispersion value for both KE penetrators and exposures across all four azimuths (0, 30, 60 and 90 degrees). In the first set of comparisons, the basic and modified DAL M and F LOF values were compared to the DS "hardware only" aggregated M and probabilities (see Table 7). The DAL was modified so that the contributions of crew, communications and acquisition components were not included in M and F LOF values since the DS "hardware only" aggregated probabilities for mobility and firepower do not include contributions from these components. In the second set, the DS kill category probabilities were aggregated such that mobility and firepower included the contributions from the other kill categories which are in the DAL LOF values (see Table 7). Also, the format of the comparisons was different; one was tabular and the other graphical.

Before discussing the implications of these comparisons, the difference in the numerical calculations of both methodologies will be discussed. The numerical comparison of the two was an apples/oranges type of comparison. However, since the DAL LOF values have been used incorrectly as probabilities for years, it was of interest to compare magnitudes. These calculations are the same once the results of each cell have been determined. The difference comes when calculating the DS probabilities and DAL LOF values for each cell. The DS calculation counts the number of times a kill definition is satisfied and divides by the number of iterations (i.e. ten). The DAL calculation involves combining the various DAL LOF values for the killed components (via the survivor rule) and taking the average LOF value over the ten iterations. It is important to note that the closer the DAL LOF value is to 1.00 for a given iteration, numerically, the closer the two calculations are to each other since achieving a LOF value of 1.00 is equivalent to satisfying a kill definition.

---

5. Gary R. Comstock, "The Degraded States Weapon Analysis Research Simulation (DSWARS): An Investigation of the Degraded States Vulnerability Methodology in a Combat Simulation", US Army Materiel Systems Analysis Activity, DRAFT, (Unclassified).

a. **Modified DAL Comparisons.** The first set of comparisons matched the Degraded States, by kill category, to the basic DAL LOF values for M, F and K. Since the DAL lumped crew, communications and acquisition into the M and F LOF values and DS provided these probabilities separately, additional DAL M and F LOF values, which excluded the crew, communications and acquisition components' contributions, were calculated and then compared. The DAL LOF values, which do not include the crew, communications and acquisition contributions, will be called the modified DAL LOF values. The probability of each kill definition was extracted from the full probability distribution and reported by kill category. The sum of the kill definition probabilities for the mobility and firepower kill categories was compared to the DAL M and F LOF values, respectively. These comparisons are contained in Appendix D.

Some explanation is required for the format of the tables in Appendix D. The top of the table shows the initial conditions for that set of results. A verbal description of the realized kill definitions and their associated probabilities are listed by kill category and are read from top to bottom. Within a kill category, if more than one individual kill definition occurred simultaneously, then the verbal descriptions are read sequentially with the associated probability found next to the last verbal entry. The kill definition probabilities are summed for each kill category and compared to the DAL LOF values. This procedure is consistent with the DAL's intended purpose of capturing both those missions that cannot be executed at all and those that can be done "less well".

There were three different cases seen in these comparisons. The first case has the basic DAL LOF value larger than the DS probability, but upon removing the contributions of the crew, communications and acquisition components, the DAL LOF value is smaller than the DS probability. In the second case, the DS probability was larger than the basic and modified DAL LOF values. The third case has both the basic and modified DAL values larger than the DS probability. Table 10 shows the percent differences between the DS probabilities and both basic and modified DAL values for all three cases. The term "hardware only" means the DS mobility and firepower probabilities are summations of probabilities of kill definitions in their respective kill categories only. The differences are reported for mobility and firepower separately. The cases refer to the 16 sets of initial conditions selected for these comparisons as described above. Although, in all 32 cases, no average difference is larger than 12 percent, the figures in Appendix D illustrate that the DS approach provides higher resolution results which give a much fuller assessment of the damage to the vehicle.

TABLE 10. Numerical Differences Between DS (Hardware Only) and DAL

Mobility Differences

Case	Basic DAL vs. DS range	Basic DAL vs. DS average	Mod DAL vs. DS range	Mod DAL vs. DS average
1) Basic DAL > DS > Mod DAL (12 cases)	1-21%	10%	0-13%	5%
2) DS > Basic DAL > Mod DAL (3 cases)	2-4%	3%	6-15%	12%
3) Basic DAL > Mod DAL > DS (1 case)	3%	3%	0%	0%

Firepower Differences

Case	Basic DAL vs. DS range	Basic DAL vs. DS average	Mod DAL vs. DS range	Mod DAL vs. DS average
1) Basic DAL > DS > Mod DAL (7 cases)	2-12%	7%	0-1%	0.8%
2) DS > Basic DAL > Mod DAL (8 cases)	0-3%	2%	0-9%	5%
3) Basic DAL > Mod DAL > DS (1 case)	2%	2%	1%	1%

There were two reasons for the first case. The basic DAL LOF value was larger because it included contributions from the crew, communications and acquisition components which are reported separately within the Degraded States approach. The DS probability was greater than the modified DAL LOF values because of the way that calculations are performed for the two methodologies. Since, numerically, every occurrence of a kill definition is equivalent to a DAL LOF value of 1.00, components which gave DAL LOF values less than 1.00 and satisfied a kill definition, caused the DAL calculations to be less than the DS calculation. This is true for both the basic and modified DAL LOF values, but it's effect on the basic DAL LOF comparisons is overcome by the contributions of the crew, communication and acquisition components.

For the mobility kill category, this case can be seen in the following figures: D-1, D-2, D-4, D-5, D-6, D-7, D-8, D-12, D-13, D-14, D-15 and D-16. Kill definitions M1 and M2 components yielded DAL LOF values ranging from 0.20 to 0.50 and 0.65 to 0.87, respectively. The higher the DS probability of these two

kill definitions, the larger the difference between the DS probability and the modified DAL LOF value. The DAL LOF value was almost always 1.00 for kill definition M3 components.

In Figures D-5, D-6, D-7, D-8, D-14, D-15 and D-16, the firepower kill category comparisons reflect the first case. Components killed when achieving kill definitions F8 and F9 yielded DAL LOF values ranging from 0.24 to 0.43 and 0.80 to 0.96, respectively. The higher the DS probability of these two kill definitions (especially F8), the greater the difference between the DS probability and the modified DAL LOF value for firepower. Kill definition F1 and F17 components yielded a DAL LOF value of 1.00 for the firepower.

The reason for the second case was different for the two kill categories. In the mobility kill category, this case was seen in Figures D-3, D-10 and D-11. In these cases, the probability of kill definition M1 (reduced speed, slight) simultaneously occurring with the "no damage" states of the other five kill categories was high. This caused both the basic and modified DAL LOF values to lag behind the DS probability. In the firepower kill category, this case occurred in Figures D-1, D-2, D-3, D-4, D-9, D-10, D-11 and D-12. The probability of satisfying crew, communications and/or acquisition kill definitions (other than "no damage") without firepower damage was low; therefore, the numerical contributions of crew, communications and/or acquisition components to the DAL LOF value were overcome relative to the DS probability by the simultaneous satisfaction of a DS firepower kill definition. Specifically, the basic and modified DAL LOF values lagged due to the occurrences of kill definitions F8 and F9.

The third case was due to the effects of the initial DAL LOF values calculated by the main SQuASH program. The basic DAL LOF value was larger for the same reason as the first case. However, the modified DAL LOF values were larger than the DS probability because the initial LOF values, which contribute to the final DAL value, have no impact on the DS probability. In the mobility kill category, this occurred in Figure D-9. In this case, 95 percent of the mobility probability came from kill definition M3 (total immobilization) whose components contribute a 1.00 to the DAL LOF value. This caused the modified DAL LOF value and the DS probability to be equivalent except for the small contribution of the initial LOFs to the DAL. The same case occurred in Figure D-13 for the firepower kill category comparison. In this case, kill definition F9 contributed DAL LOF values close to 1.00. Along with the other two kill definitions (F1 and F17), this caused the two methodologies to be numerically equivalent in magnitude except for the contribution of the initial LOF values.

There are two general observations concerning the above comparisons which need to be mentioned. First, the vehicle degraded state combination(s) which had the most impact on these comparisons was the simultaneous occurrence of the "no damage" state for mobility or firepower and some crew, communications and/or acquisition kill definition(s). These occurrences contributed to the basic DAL LOF

value, but not to the DS probability or the modified DAL value; therefore, the higher the probability of these occurrences, the greater the basic DAL LOF value was relative to the DS probability. Using the full probability distribution of vehicle degraded states (see section IV.1) for the various sets of initial conditions, it was determined that this combination of kill definitions was more likely to occur in the mobility than the firepower kill category. The second observation is that the Degraded States approach, with its robust metrics, provided more information on the vehicle's damage assessment. The DS assessment was more informative because the kill definitions and their probabilities were calculated for six different kill categories as opposed to a LOF value for only two kill categories. Since the DS probability represented the sum of the probabilities of the kill definitions in that kill category and the DAL value represented total loss of function to the vehicle, numerical agreement could be misleading.

b. **Aggregated DS Probability Comparisons.** The second set of comparisons took the opposite approach from the first. That is, the first set extracted, from the DAL LOF value, the contributions of kill categories which were not included in the DS probability, while the second set added them to the DS probability. These comparisons were made for the same set of initial conditions as the first set. The basic DAL M, F and M/F LOF values were used. The DS probabilities aggregated the kill categories which contributed to the DAL. Table 7 illustrates how the DS aggregated M, F, K and M or F probabilities are calculated. When aggregating ammunition into the mobility and firepower probabilities, kill definition K4 was not included. Catastrophic events were implicitly included since the most severe kill definition for each kill category was selected upon the occurrence of a K-kill. In order to make these aggregations, the kill categories were assumed to be independent of one another, an assumption which is no worse than present practice with the DAL metrics. The DS probabilities denoted as "hardware only" are also described in Table 7. All comparisons were made at 1 kilometer with a 2 foot dispersion value and are contained in Appendix E.

These aggregated comparisons exhibit similar trends between the two methodologies. As seen in Figures E-1 through E-12, the aggregated DS probabilities were always larger than the DAL LOF values because of the difference in the way the two values are calculated. The comparisons of the DS "hardware only" probabilities to the DAL LOF values were discussed in the preceding section of this report. The differences in magnitude between the two methodologies were calculated for the aggregated comparisons and a summary of the percent differences are provided in Table 11 for M, F and M or F. The firepower comparisons exhibited closer agreement because the probability of simultaneously achieving the "no damage" state and some damage to another kill category was lower than for the mobility kill category; therefore, both the basic DAL LOF value and the aggregated DS probability were numerically closer to the DS "hardware only" probability for firepower. This phenomenon was more pronounced for the hull defilade results. Similar results were obtained for identical

comparisons made at ranges of 2 and 3 kilometers with dispersion values of 5 and 10 feet, respectively.

TABLE 11. Numerical Differences Between Aggregated DS and DAL

Aggregated DS > DAL

	M		F		M or F	
Exposure	range	average	range	average	range	average
Fully	3-18%	12%	2-12%	7%	1-9%	6%
Defilade	3-24%	14%	2-6%	4%	2-5%	4%

V. Summary

As the results in this report illustrate, the Degraded States methodology provides a more detailed assessment of the vehicle's damage than can be obtained using the DAL approach. The Degraded States approach assesses the damage in terms of six different vehicle kill categories (mobility, firepower, acquisition, crew, communications and ammunition). For a given damage to the vehicle, a kill definition for each of the six kill categories is determined based on the critical components killed. The probabilities of the various combinations of the kill definitions for each kill category are then calculated. The DS probability distribution explicitly shows how frequently the vehicle could complete its mission and how frequently it could do "less well" at its mission.

The Phase II results were provided to AMSAA for support in demonstrating the new metrics in force-level modeling. The DS full probability distribution, DS aggregated probabilities and DAL LOF values for all the initial condition combinations were provided to AMSAA as input to the force-level model, DSWARS. DSWARS ran both methodologies to allow for comaprisons of results.

Numerically, the DS aggregated probabilities were compared with the DAL LOF values and the percent differences are shown in Table 11. To compare the numerical results of the two methodologies, the DS probability distribution was aggregated to represent the damage in terms of mobility and firepower only. Although the percent differences, on the average, are not higher than 14 percent, a more rigorous statistical analysis must be performed to determine the statistical significance of the differences between the results of the two methodologies. An analysis of variance (ANOVA) will be performed on the aggregated DS probabilities and DAL LOF values. The ANOVA will determine if the difference in the results of the two methodologies are statistically significant. A BRL technical report[6] will fully document this effort and is forthcoming. Finally, the ability to

make numerical comparisons between the two methodologies shows that the Degraded States approach can provide both a detailed account of the damage assessment and an aggregated set of results analogous to the traditional set.

The sensitivity comparisons of the two methodologies indicate similar trends. The Degraded States and DAL results were analyzed for their sensitivity to the various initial conditions (range, dispersion, azimuth, exposure and threat). These excursions, found in Appendix C, exhibit similar sensitivities for the two methodologies to these initial conditions for this vehicle. A quantitative statistical test of these sensitivities will be completed in the ANOVA.

A recommendation as a result of this analysis, is that, the DS methodology should be extended to other targets and classes of targets. Calculation of the more robust metrics for other classes of targets will provide a more detailed account of their vulnerability than is presently available.

Combined with AMSAA's proof that DS results can be practically implemented in force-level modeling, sufficient evidence exists for the Army to relinquish its reliance on the DAL methodology in favor of the Degraded States. This report demonstrates the feasibility of using this methodology in assessing view average vulnerability estimates.

---

6. Jill H. Smith, "Quantitative Analyses of Vulnerability/Lethality Models", USA Ballistic Research Laboratory, DRAFT, (Unclassified).

REFERENCES

1. J. M. Abell, L. K. Roach, M. W. Starks, "Degraded States Vulnerability Analysis", USA Ballistic Research Laboratory, TR-3010, June 1989, (Unclassified).

2. Aivars Ozolins, "Stochastic High-Resolution Vulnerability Simulation for Live-Fire Programs,"*The Proceedings of Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA),*" held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988, (UNCLASSIFIED).

3. Paul H. Deitz, Aivars Ozolins, "Computer Simulations of the Abrams Live-Fire Field Testing," USA Ballistic Research Laboratory, MR-3755, May 1989, (UNCLASSIFIED).

4. Joseph J. Ploskonka, Theodore M. Muehl, Cynthia J. Dively, "Criticality Analysis of the M1A1 Tank," US Army Ballistic Research Laboratory, BRL-MR-3671, June 1988, (UNCLASSIFIED).

5. Gary R. Comstock, "The Degraded States Weapon Analysis Research Simulation (DSWARS): An Investigation of the Degraded States Vulnerability Methodology in a Combat Simulation", US Army Materiel Systems Analysis Activity, DRAFT, (Unclassified).

6. Jill H. Smith, "Quantitative Analyses of Vulnerability/Lethality Models", USA Ballistic Research Laboratory, DRAFT, (Unclassified).

APPENDIX A

Degraded States Fault Trees

INTENTIONALLY LEFT BLANK.

This appendix contains the fault trees developed for each of the Degraded States kill definitions used in this analysis. Components and/or systems are listed in either series or parallel. If in series, the loss of any component or system will result in the tree being cut; if in parallel, all components and/or systems must be killed in order to cut the tree. A kill definition is achieved if no uninterrupted path exists from the single asterisk to the double asterisk.

INTENTIONALLY LEFT BLANK.

STATE M1 - Reduced speed - slight

*

intermediate road wheels - 2

intermediate road wheels - 3

intermediate road wheels - 4

right support roller - 1

right support roller - 2

left support roller - 1

left support rolier - 2

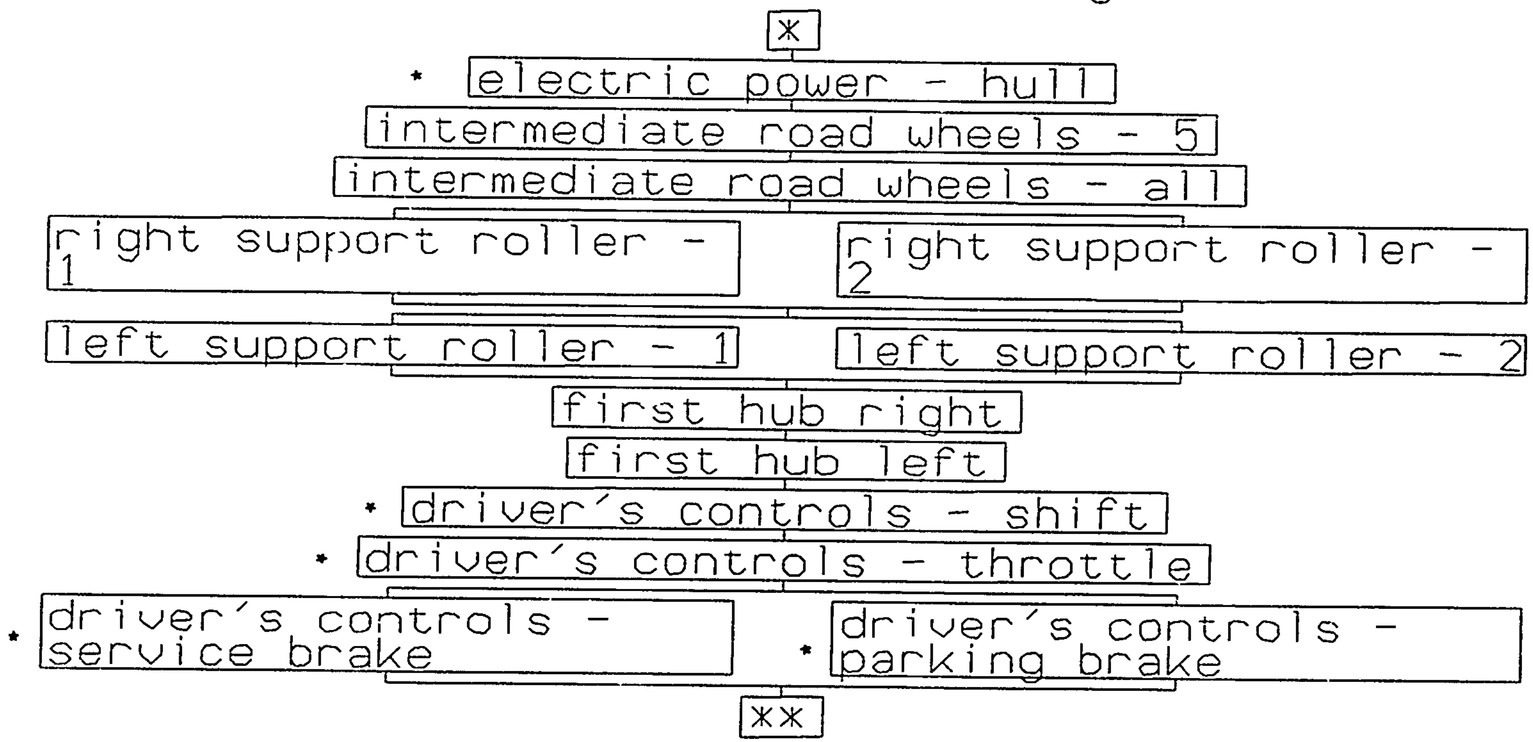
road wheel no. 7 - right

road wheel no. 7 - left

driver's controls - service brake

**

STATE M2 - Reduced speed - significant



* denotes a system of components

STATE M3 - Total immobilization

[*]

* [engine power]

* [engine power transfer]

[final drive right]

[final drive left]

* [fuel control system]

* [track tension/motion right]

* [track tension/motion left]

[track edge]

* [driver's controls - steer]

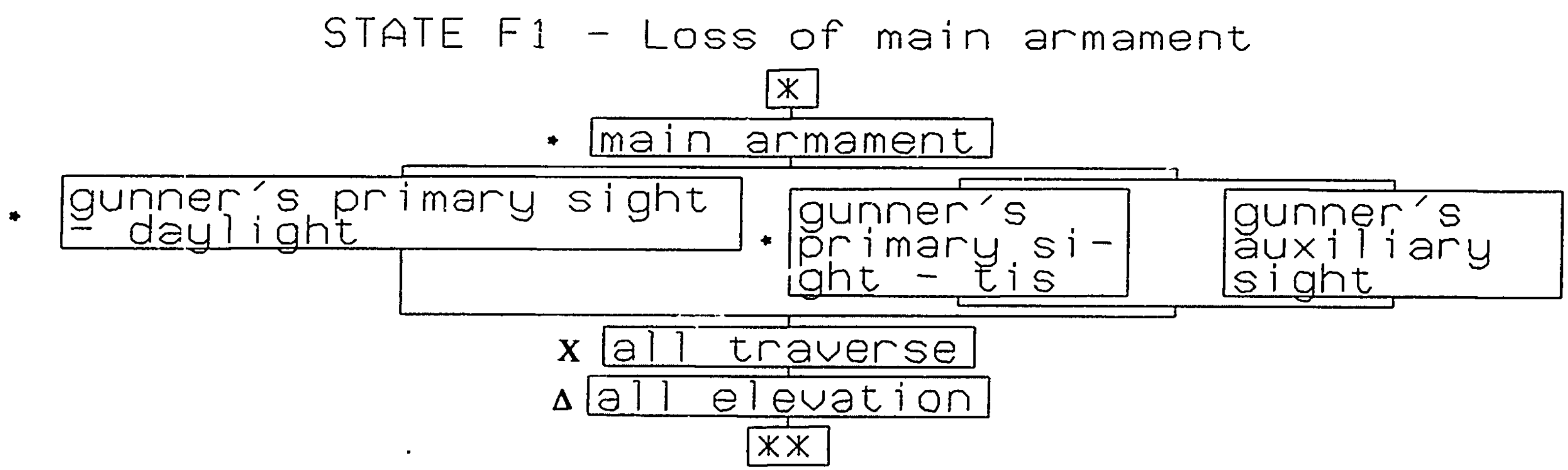
* [vehicle electric power]

[cable 2w104]

[cable 2w105-9]

[**]

* denotes a system of components

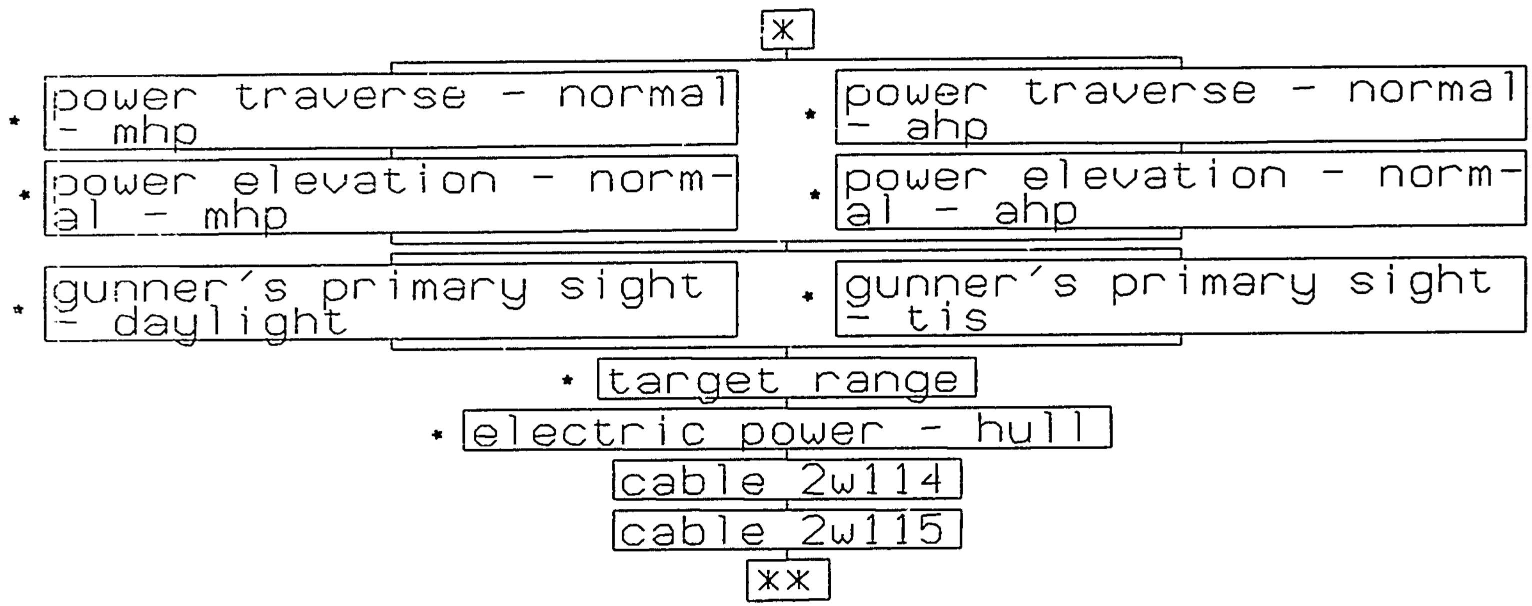


X
* power traverse - normal -mhp
* power traverse - normal - ahp
* power traverse - emergency - mhp
* power traverse - emergency - ahp
* manual traverse

Δ
* power elevation - normal - mph
* power elevation - normal - ahp
* power elevation - emergency - mph
* power elevation - emergency - ahp
* manual elevation

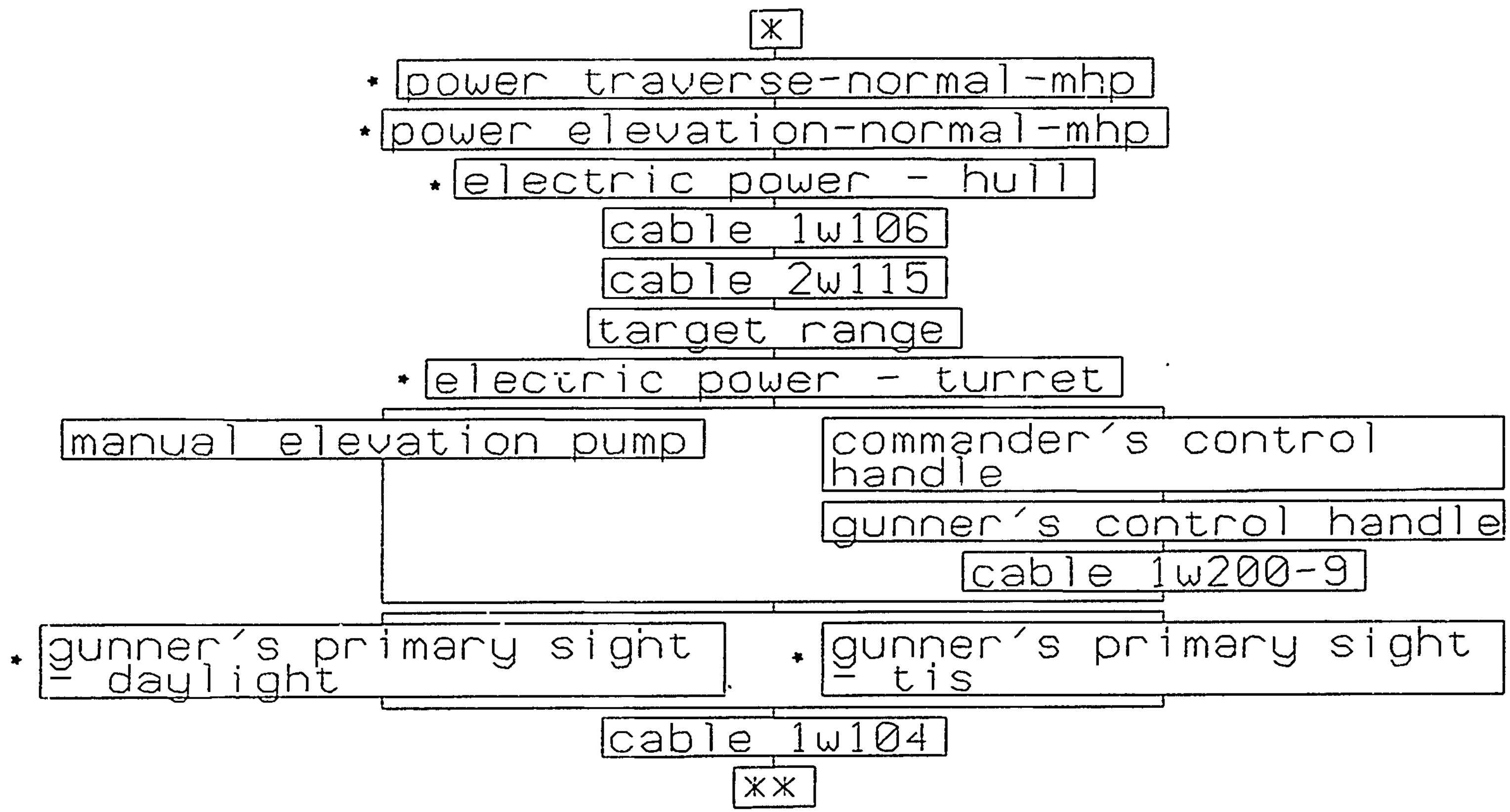
* denotes a system of components

State F2 - Unable to fire on the move



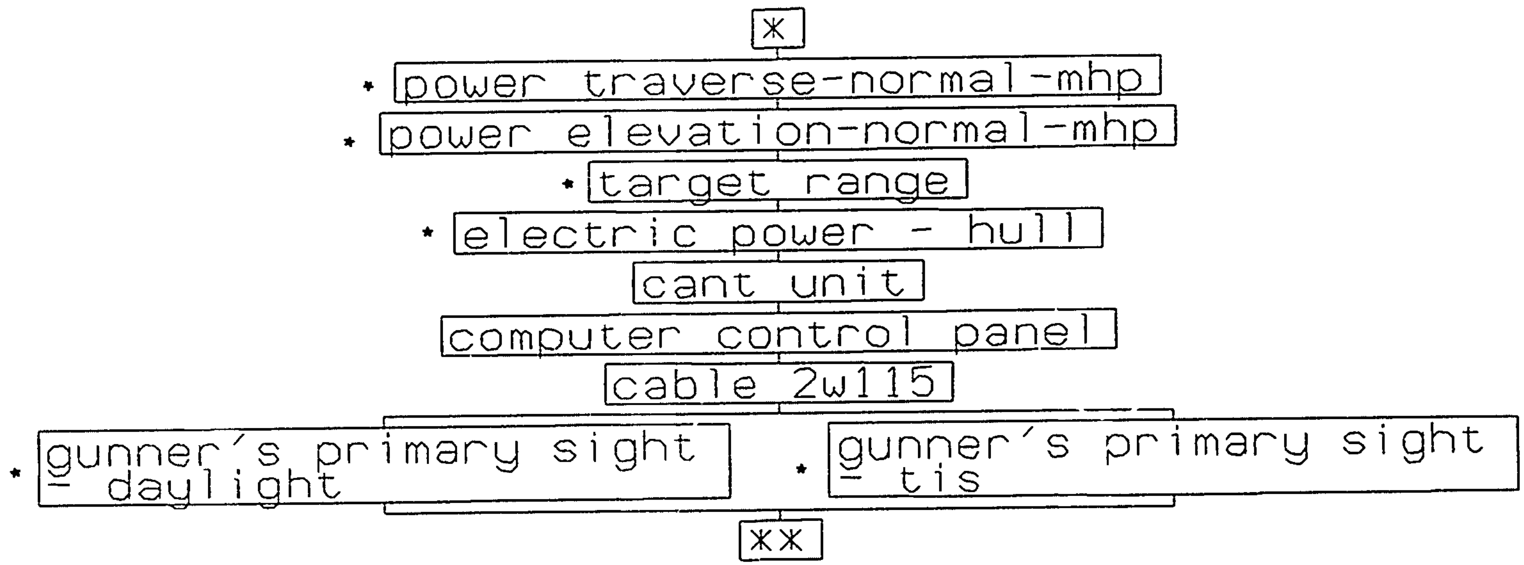
* denotes a system of components

STATE F3 - Increased time to fire



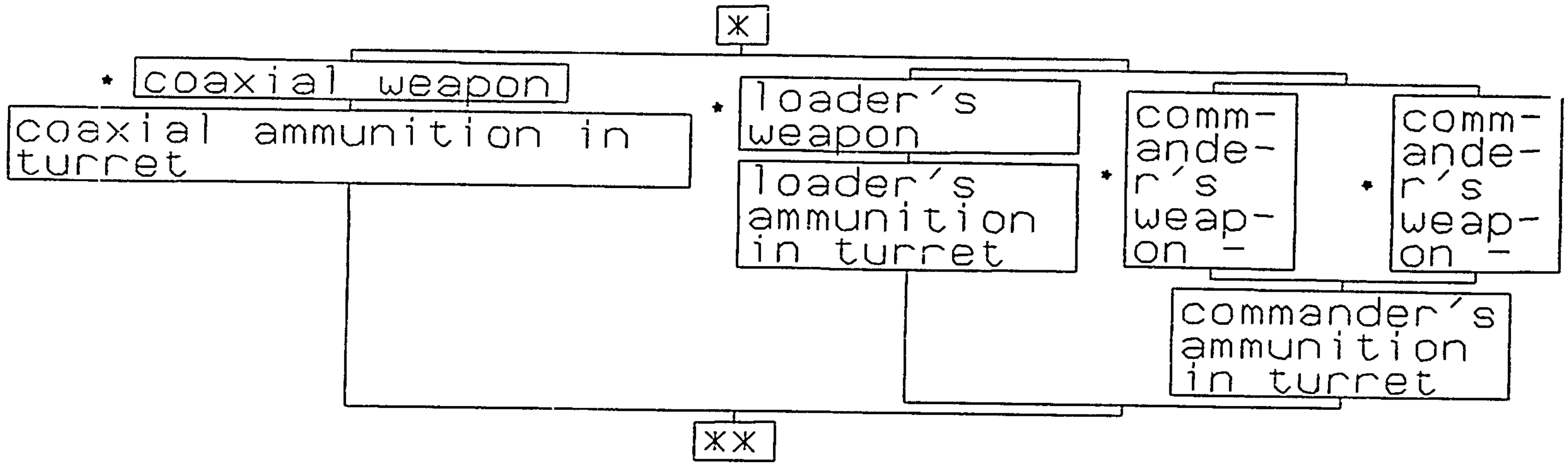
* denotes a system of components

STATE F4 - Reduced delivery accuracy



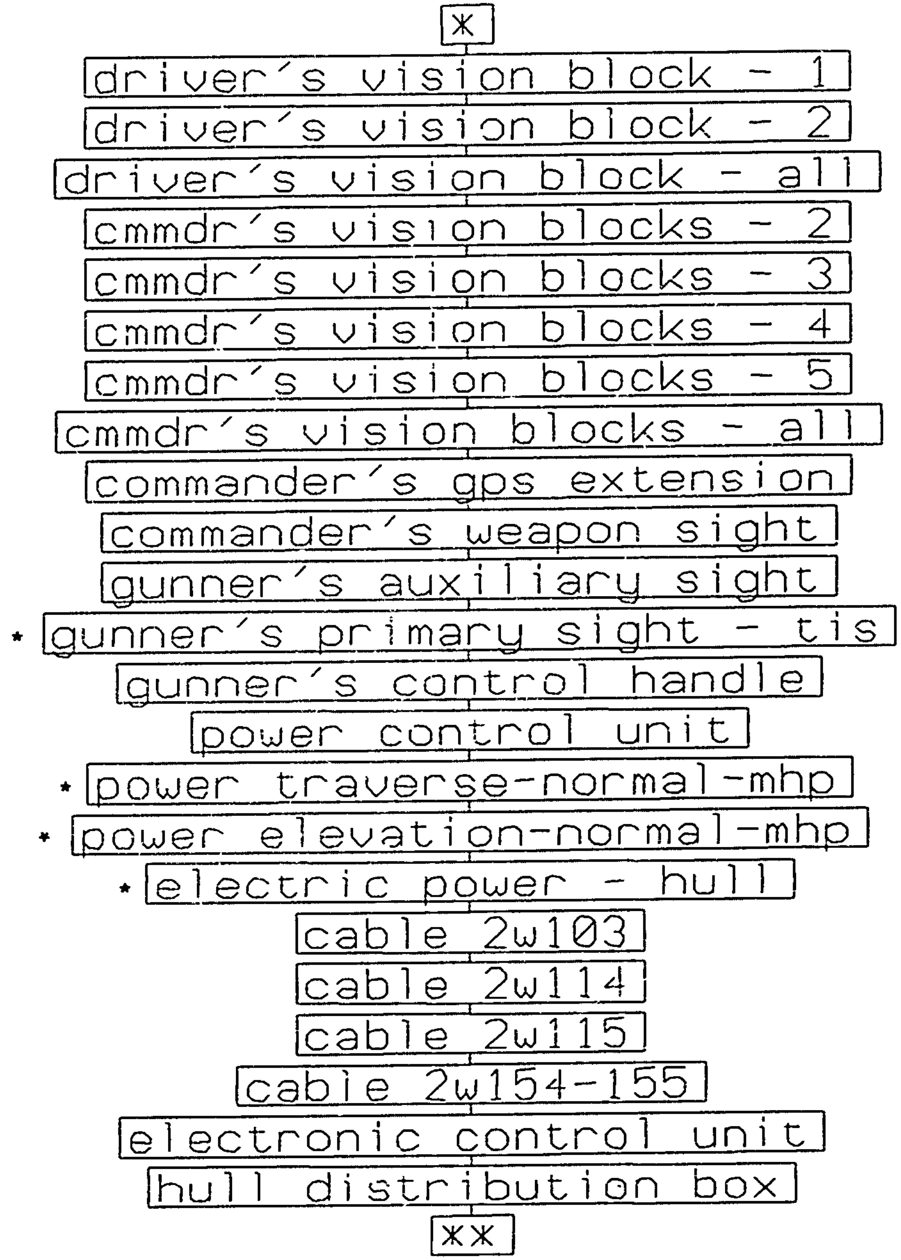
* denotes a system of components

STATE F5 - Loss of secondary armament



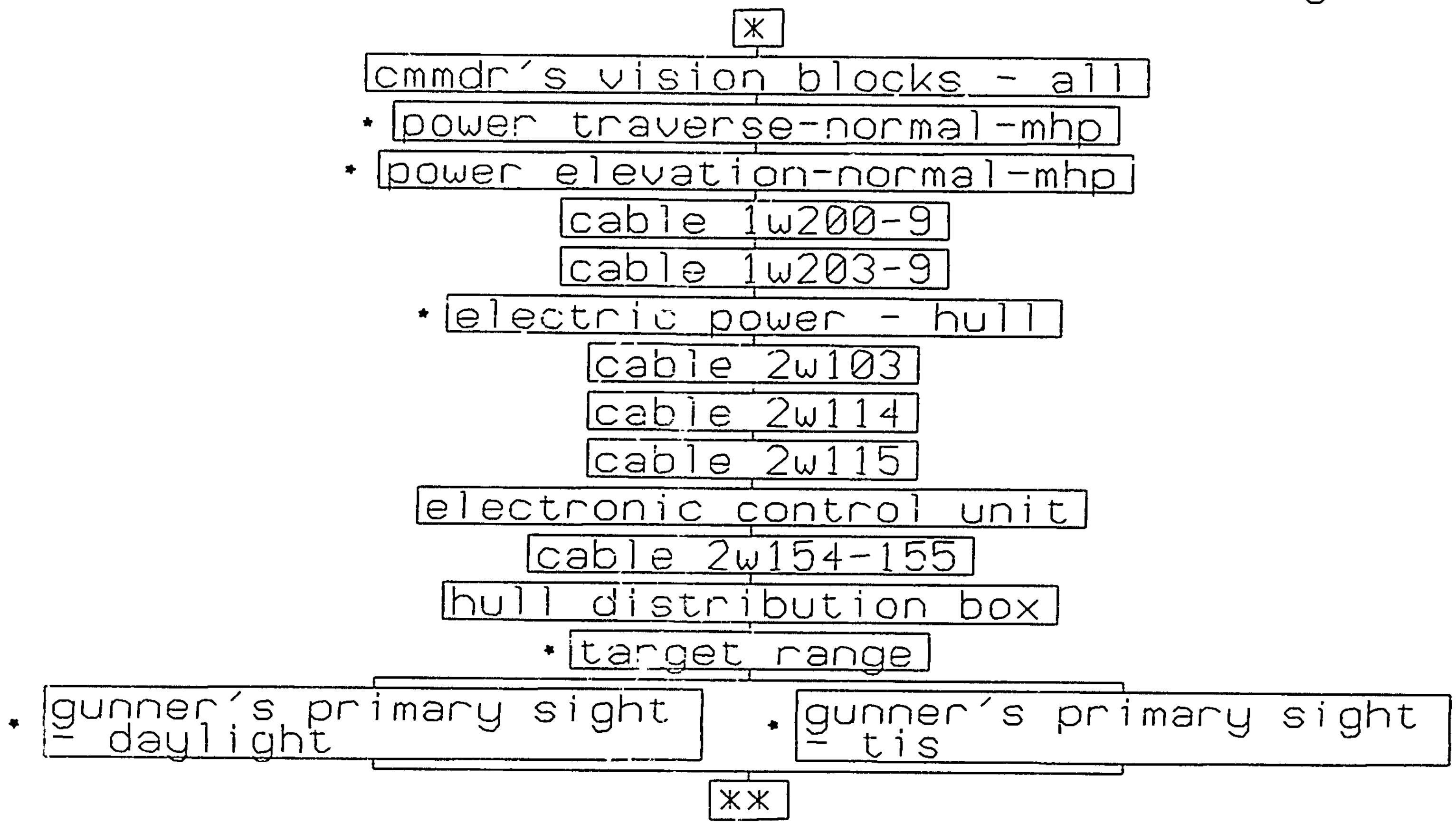
* denotes a system of components

STATE A1 - Reduced acquisition capability



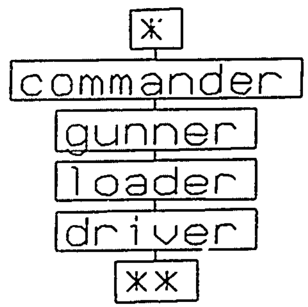
* denotes a system of components

STATE A2 - Unable to acquire while moving

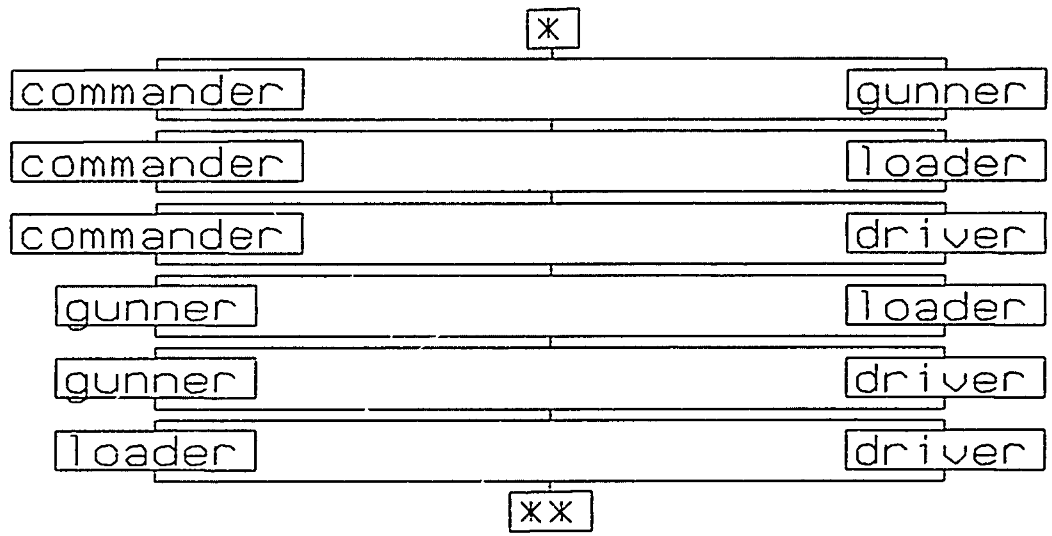


* denotes a system of components

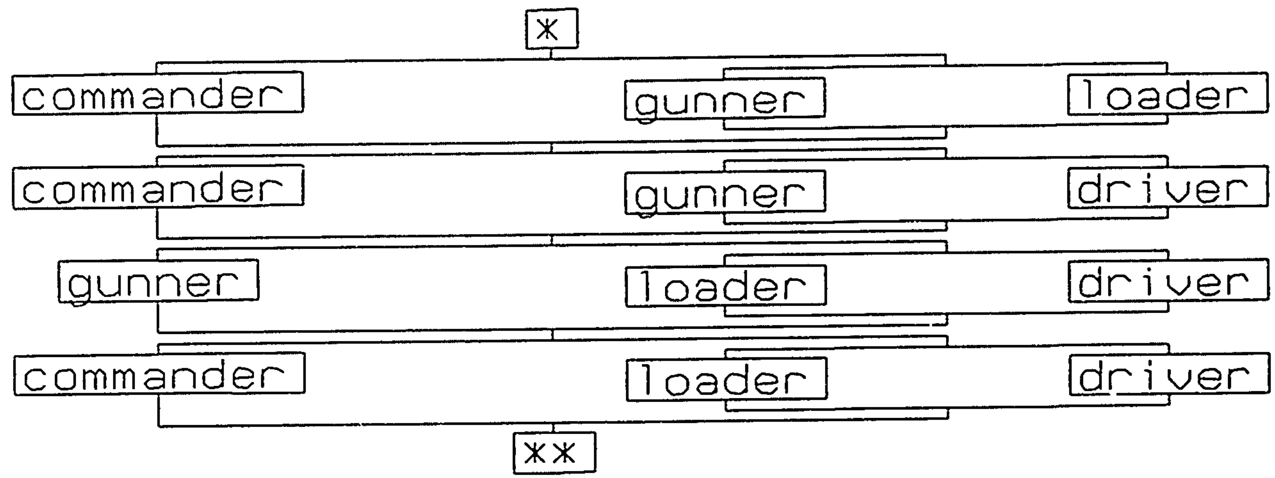
State C1 - one crew casualty



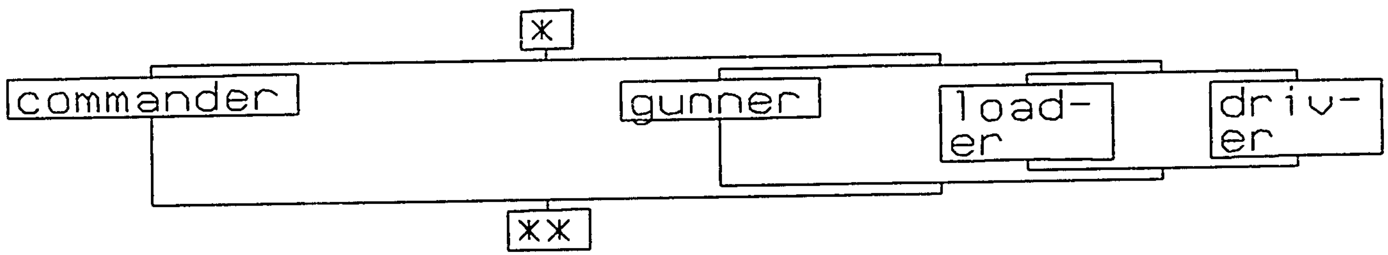
State C2 - two crew casualties



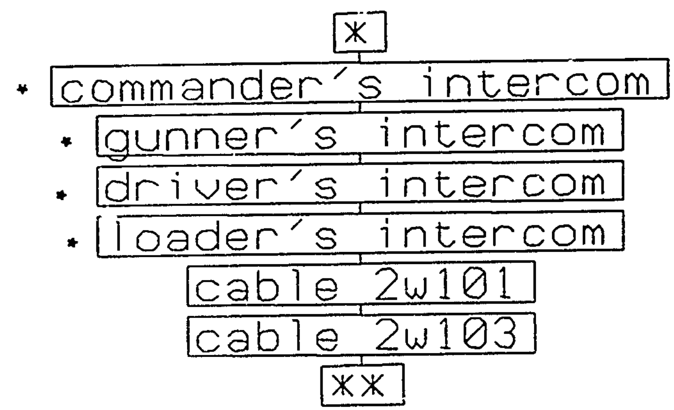
State C3 - three crew casualties



State C4 - four crew casualties

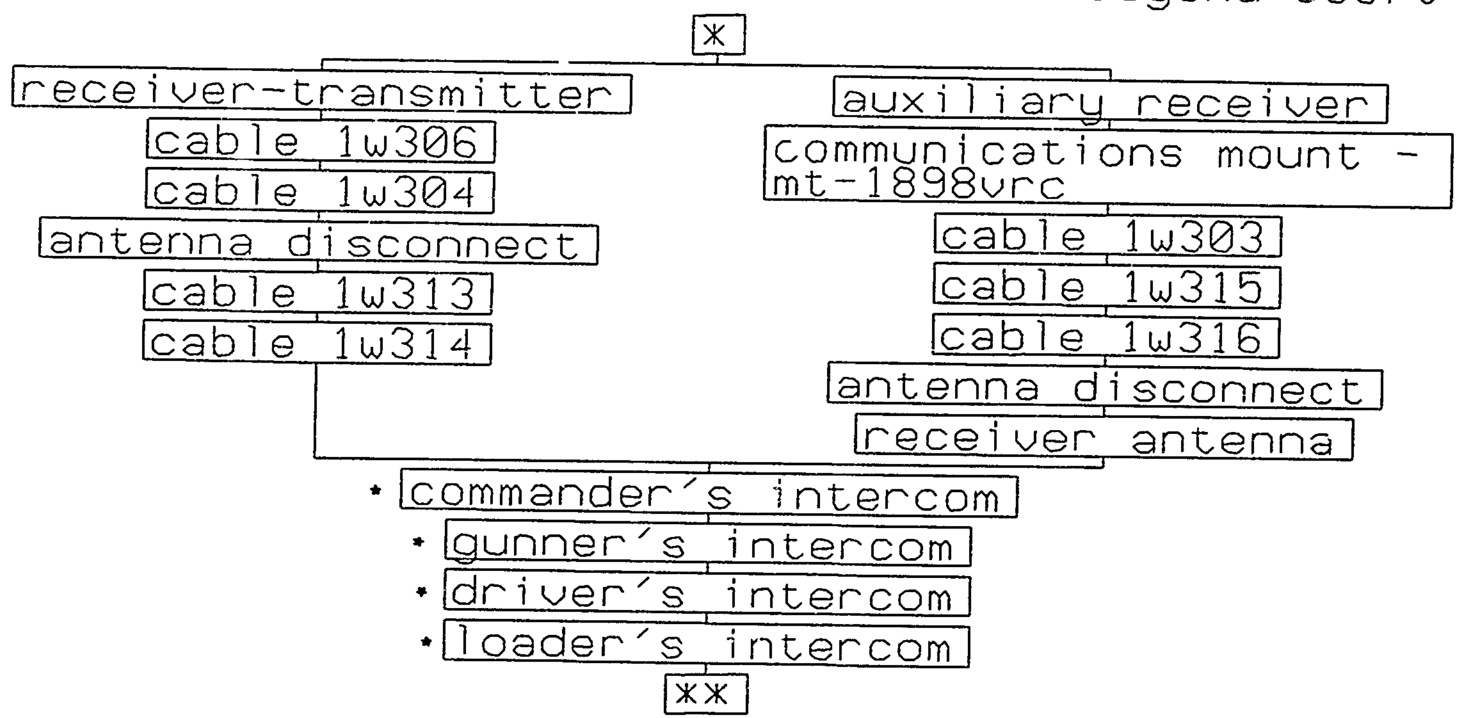


State X1 - No internal communication



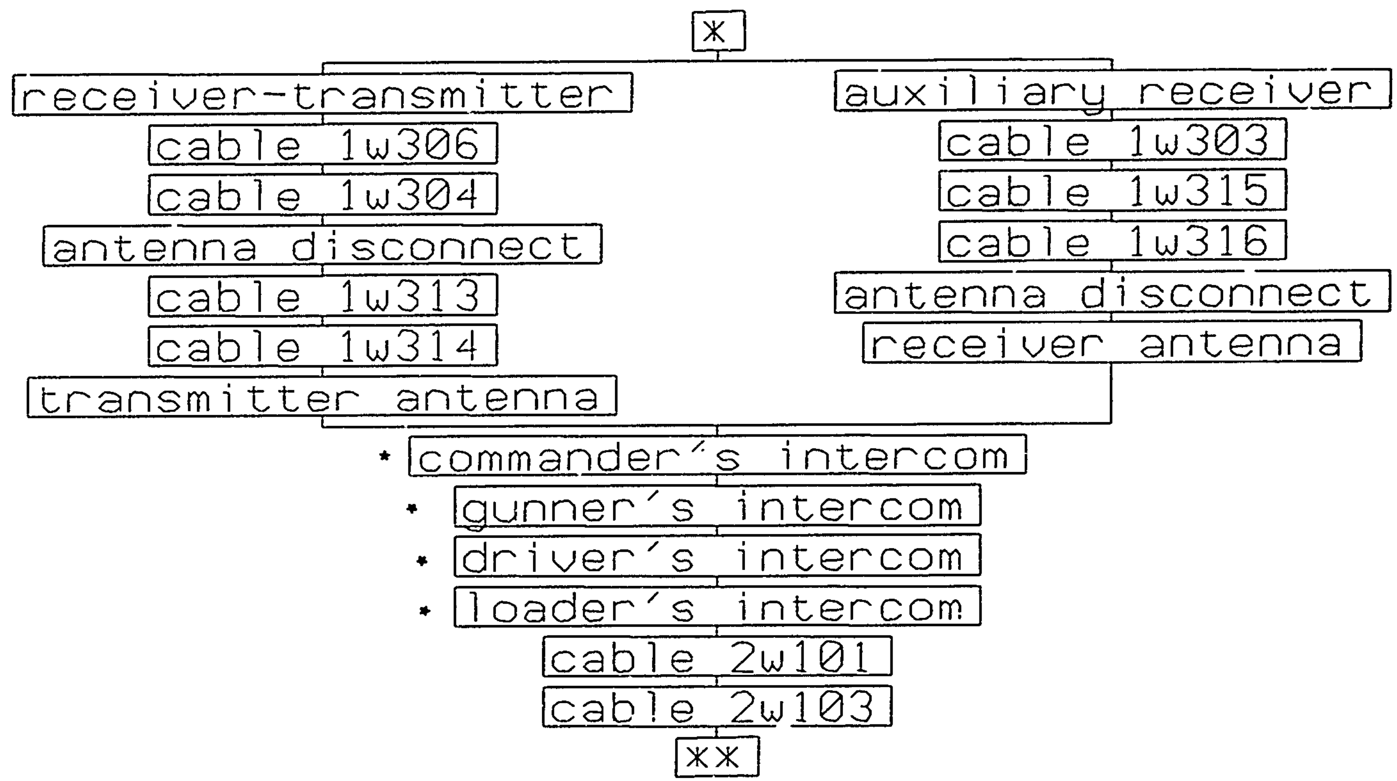
* denotes a system of components

State X2 - No external communication beyond 300ft



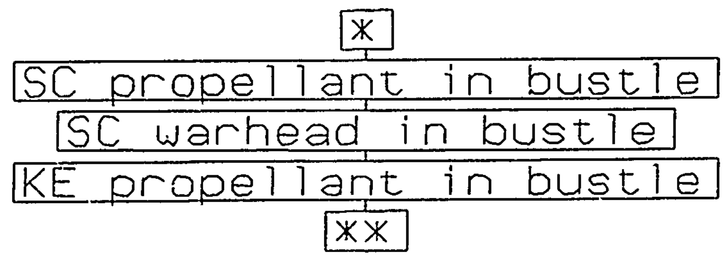
* denotes a system of components

State X3 - No external communication

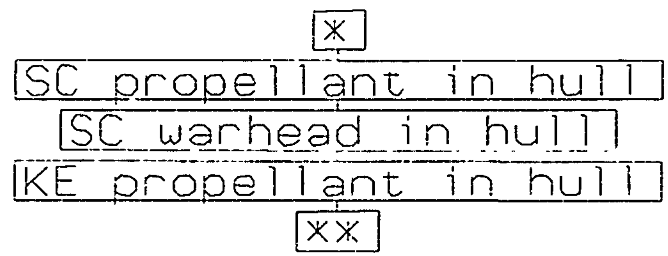


* denotes a system of components

STATE K1 - Bustle ammo lost - no K kill



STATE K2 - Hull ammo lost - no K kill



INTENTIONALLY LEFT BLANK.

APPENDIX B

Individual Cell Plots

INTENTIONALLY LEFT BLANK.

The color coded cell plots are contained in this appendix. The plots show either the DS probabilities or DAL LOF values for each cell given a hit to the vehicle. These results assumed that each cell had the same probability of being hit (i.e. unweighted).

INTENTIONALLY LEFT BLANK.

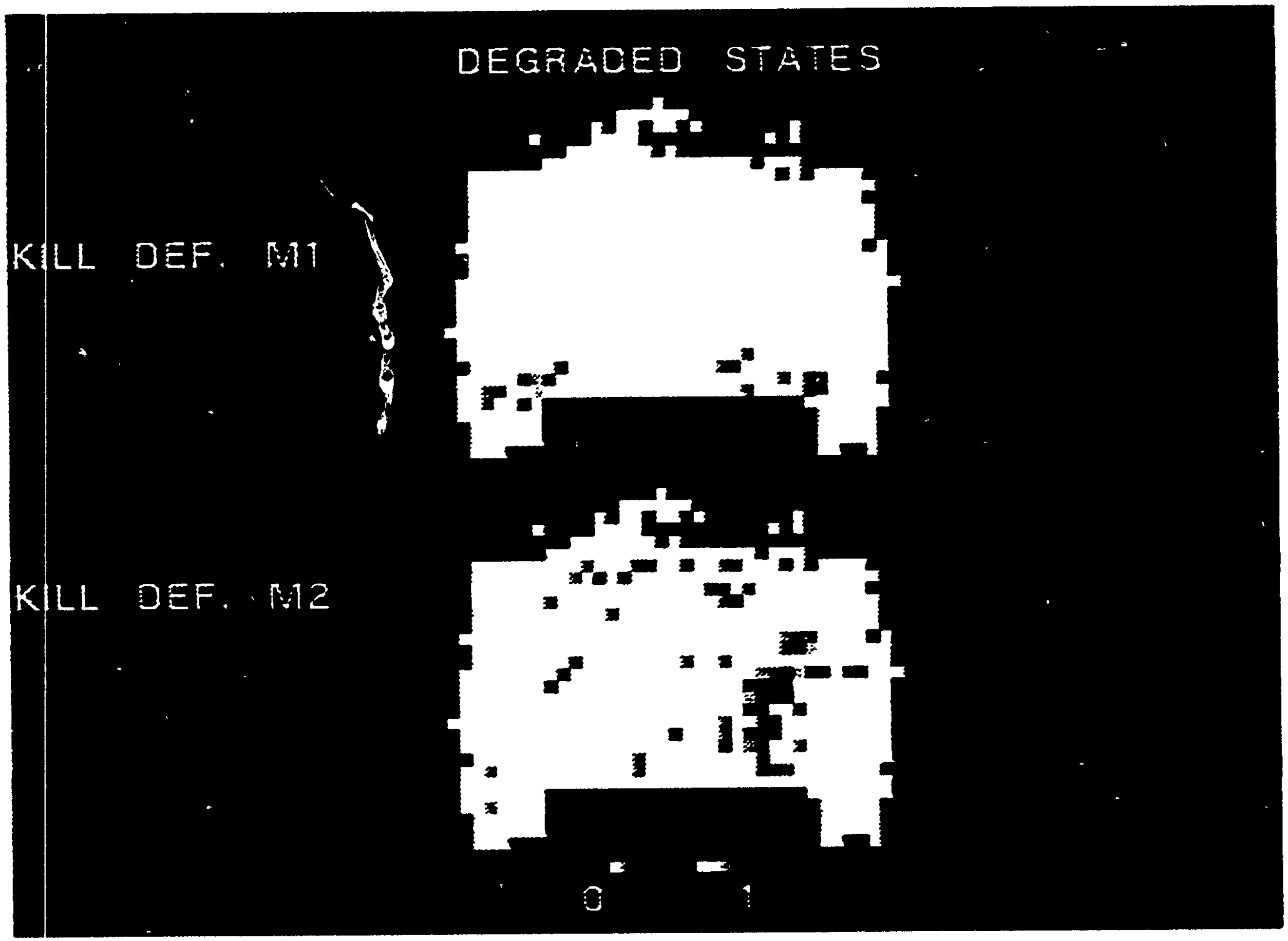


Figure B-1. Reduced speed, slight (M1) and significant (M2) cell plots

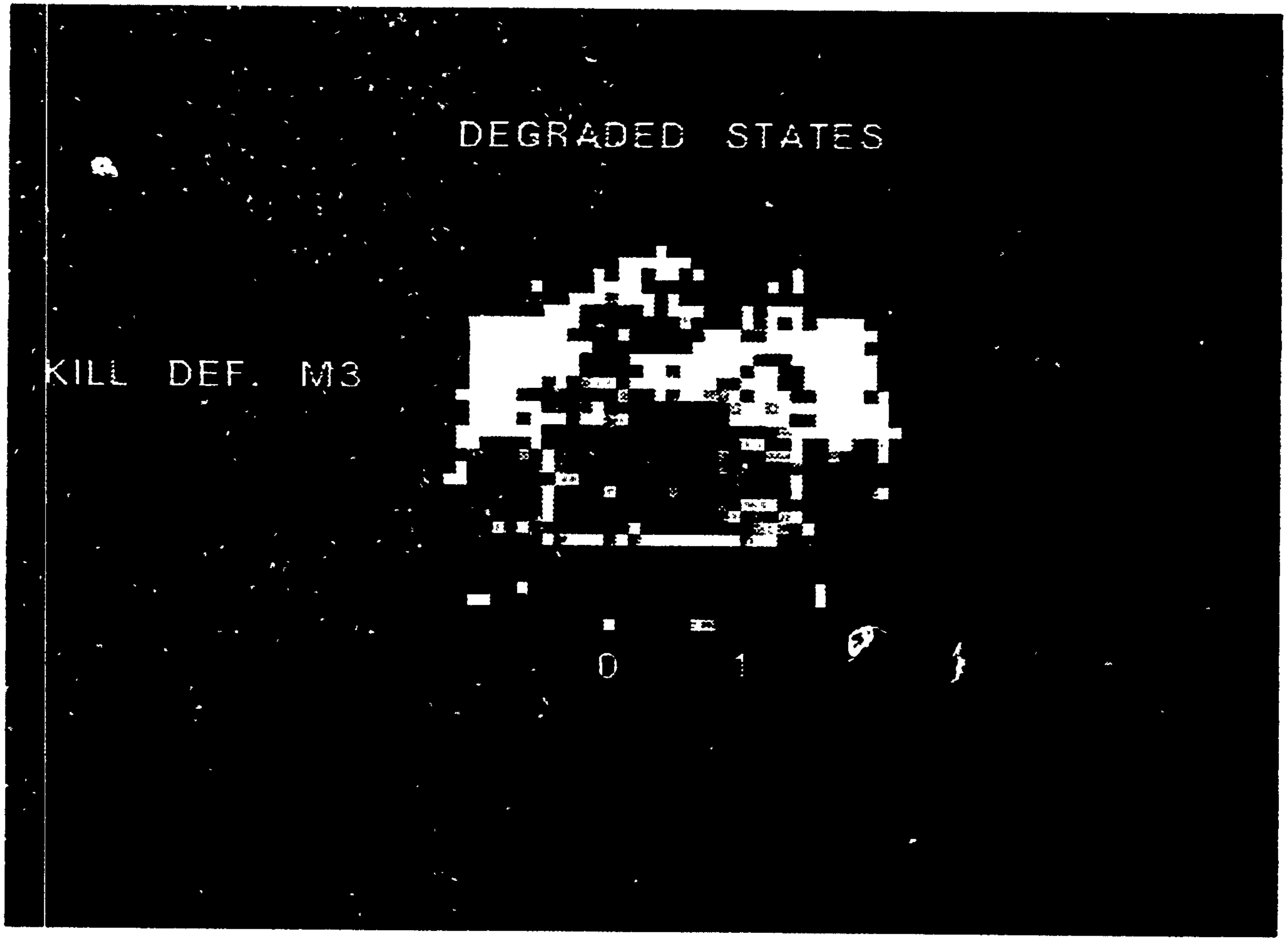


Figure B-2. Total immobilization (M3) cell plot

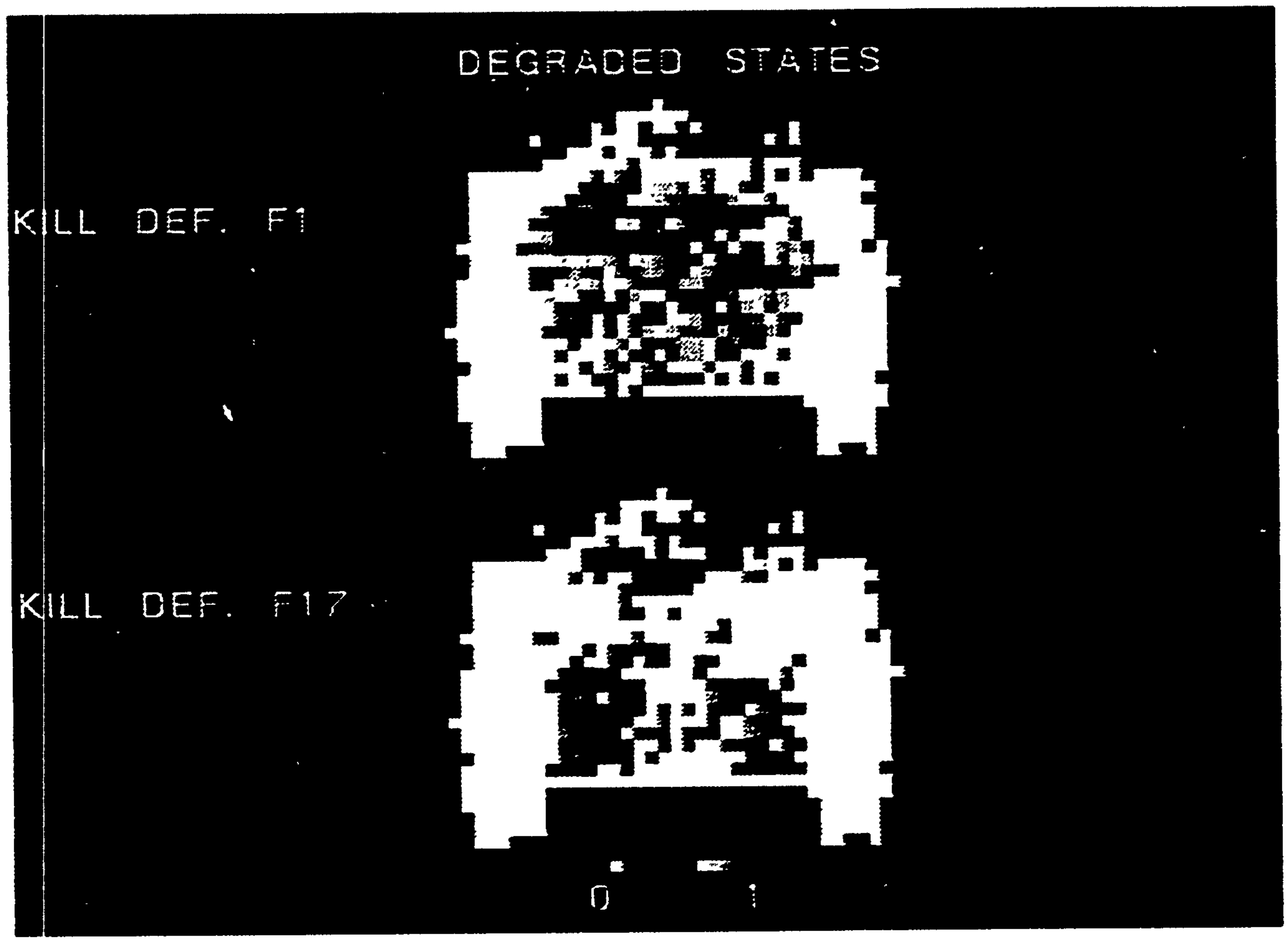


Figure B-3. Loss of main armament (F1) and loss of main armament and secondary armaments (F17) cell plots

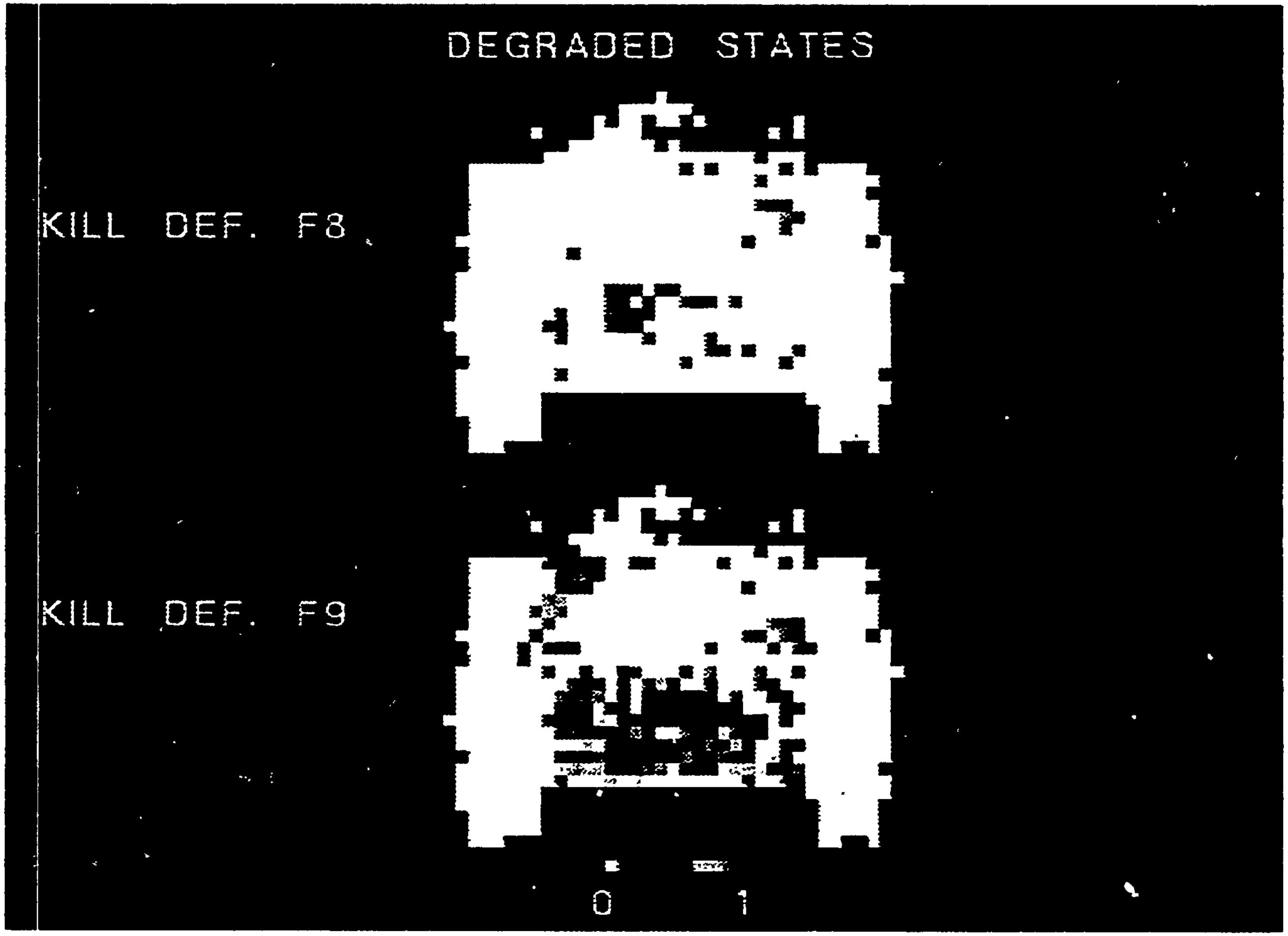


Figure B-4. Increased time to fire and reduced delivery accuracy (F8) and unable to fire on the move and increased time to fire and reduced delivery accuracy (F9) cell plots

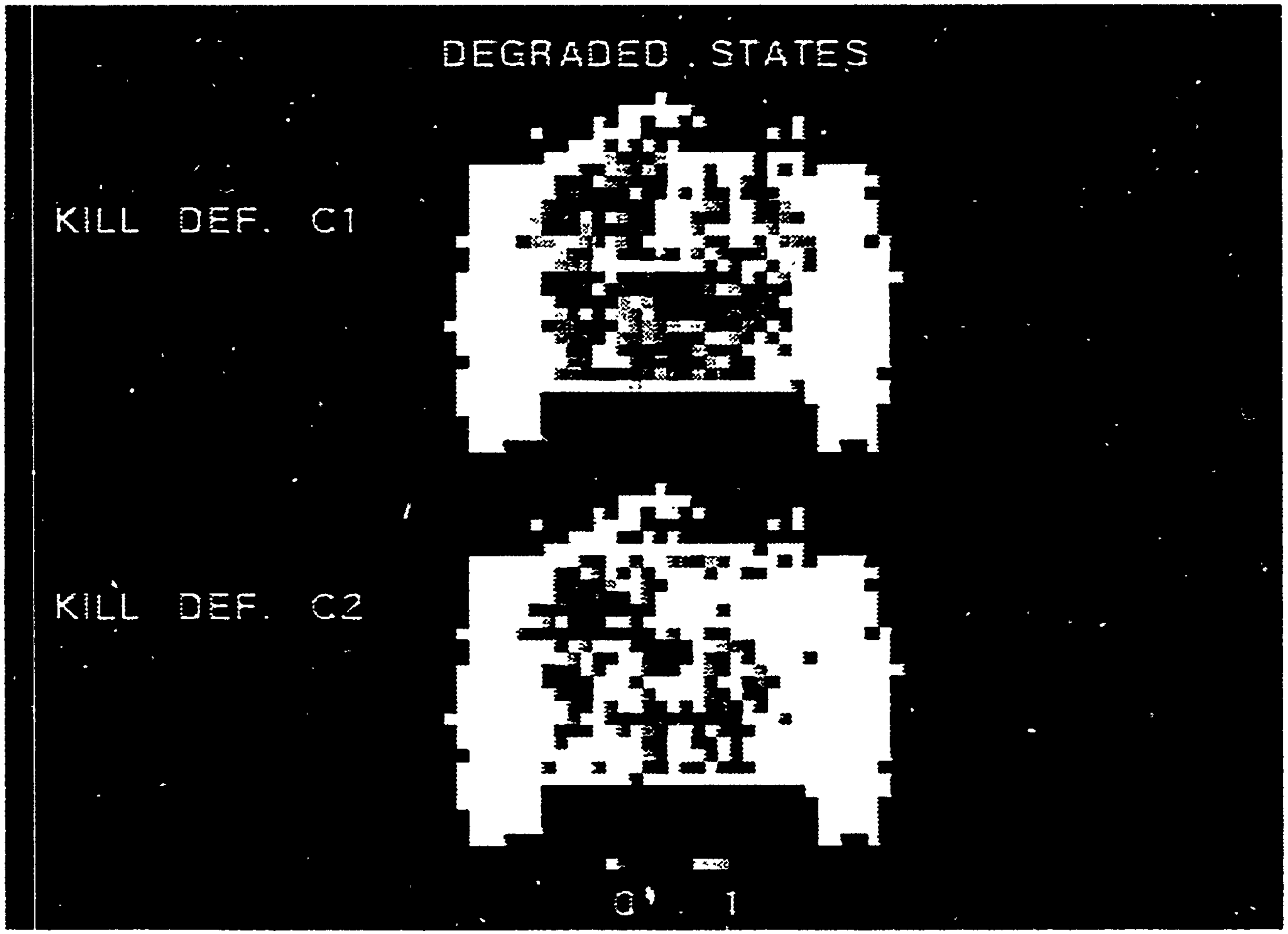


Figure B-5. One (C1) and two (C2) crew casualties cell plots

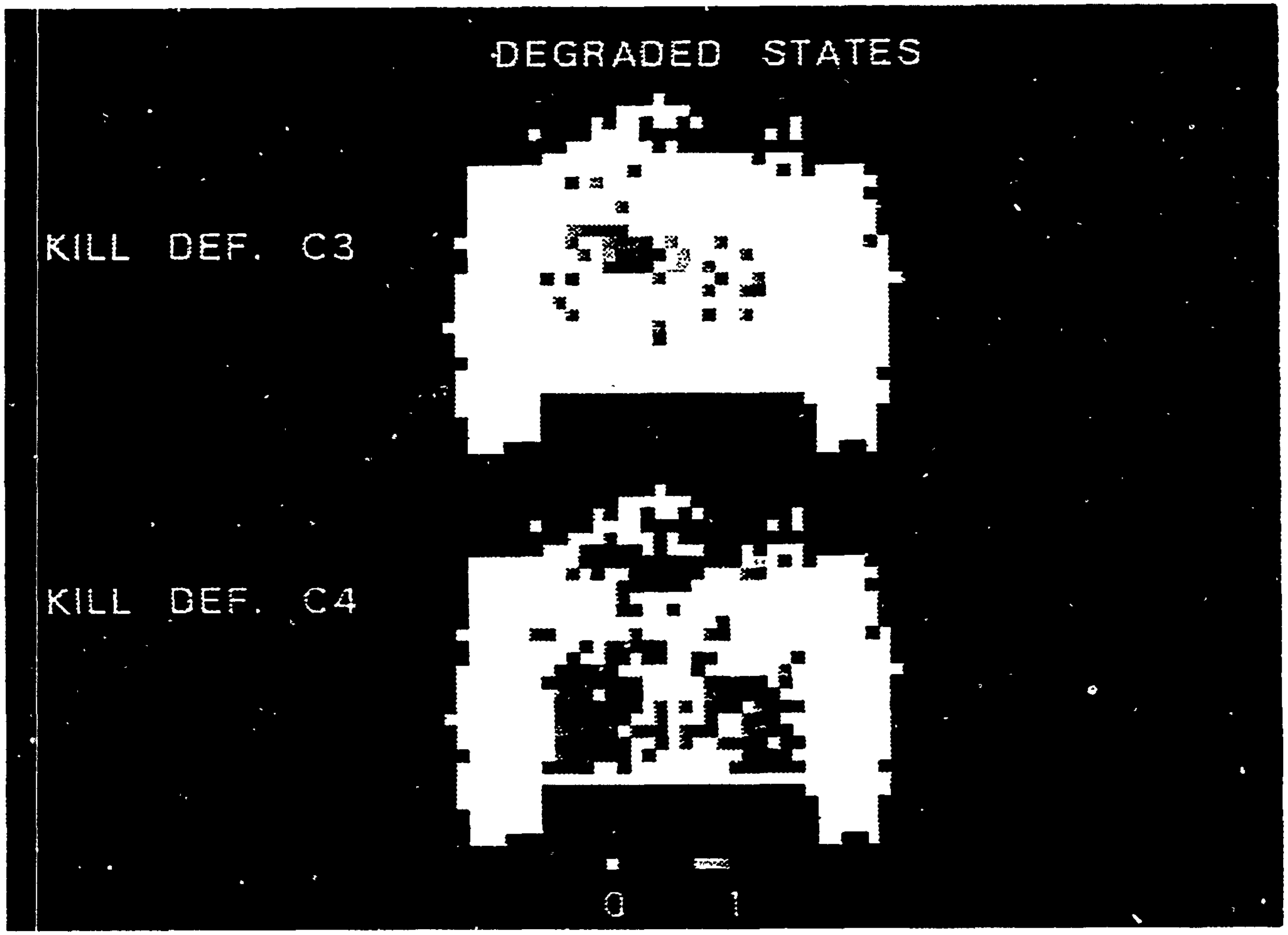


Figure B-6. Three (C3) and four (C4) crew casualties cell plots

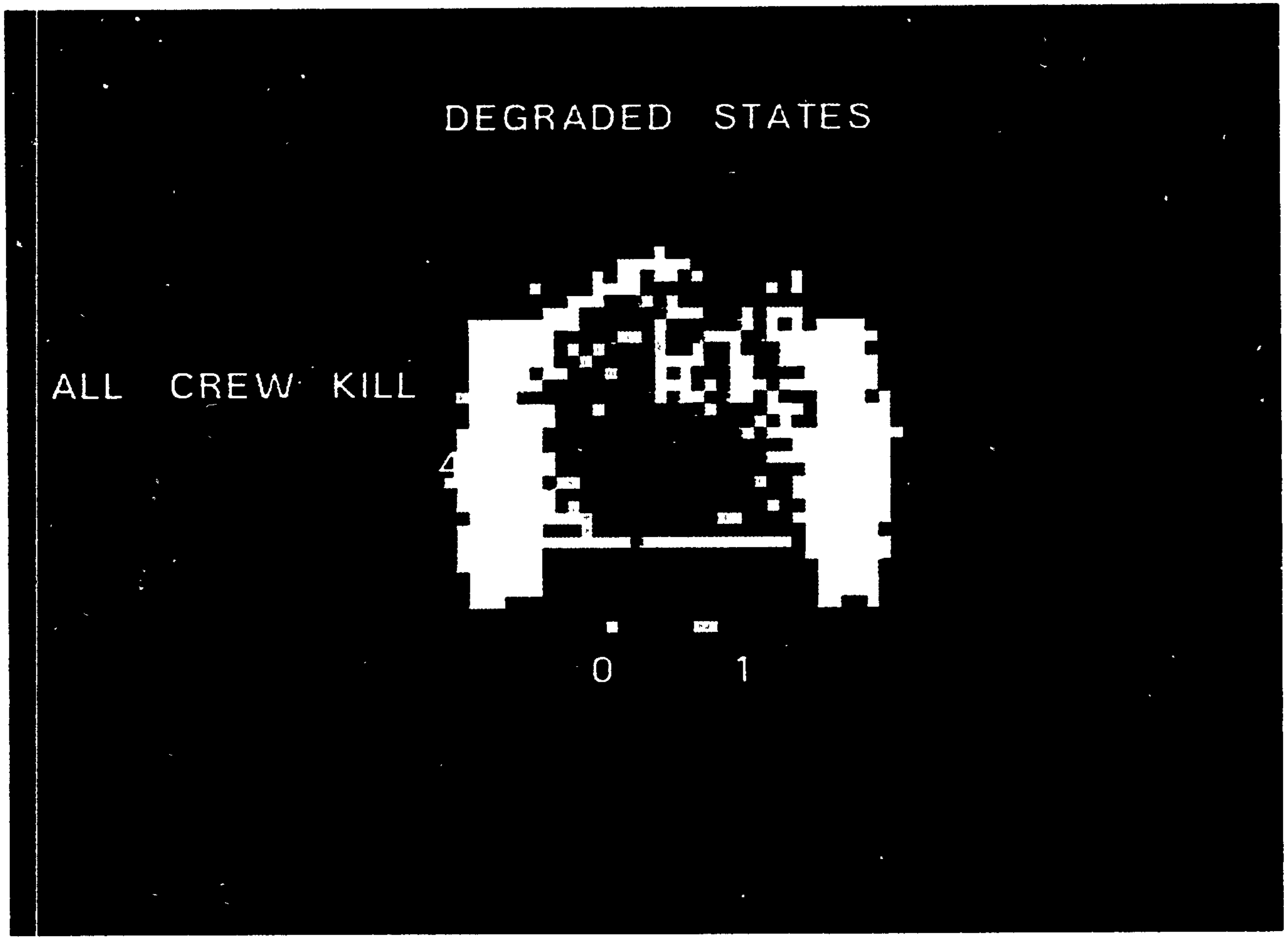


Figure B-7. All crew casualties cell plot

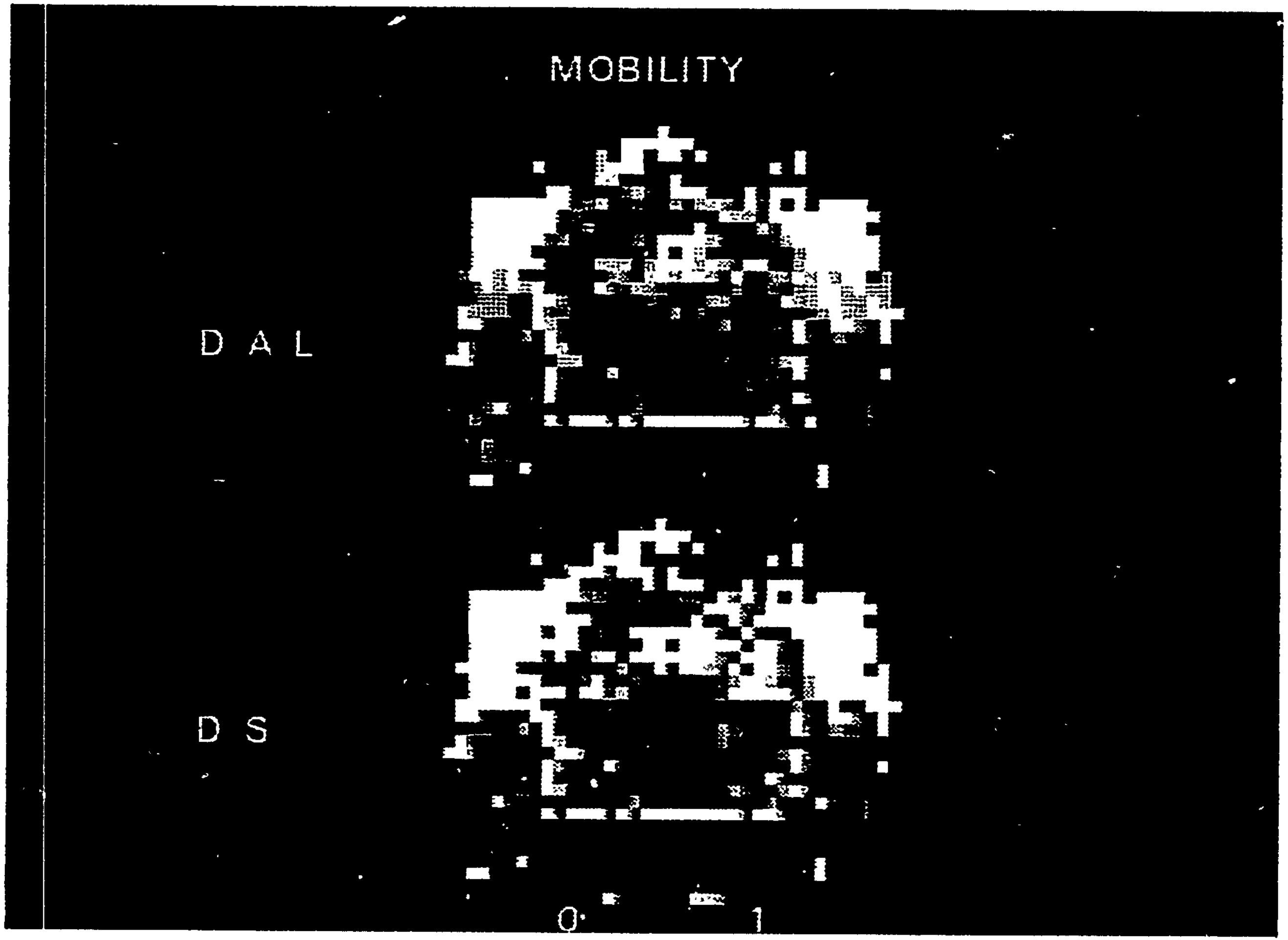


Figure B-8. DAL vs. DS mobility comparison

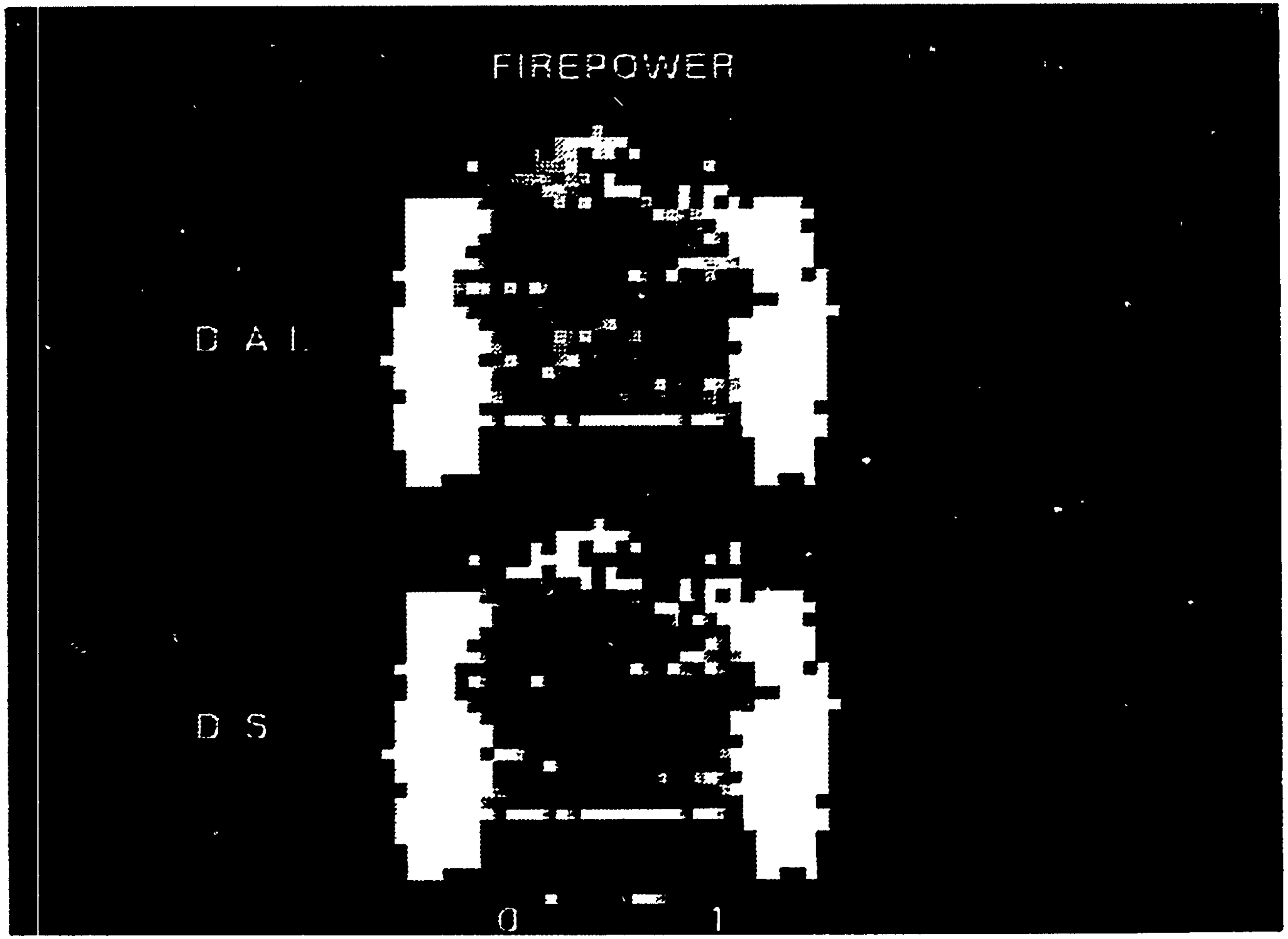


Figure B-9. DAL vs. DS firepower comparison

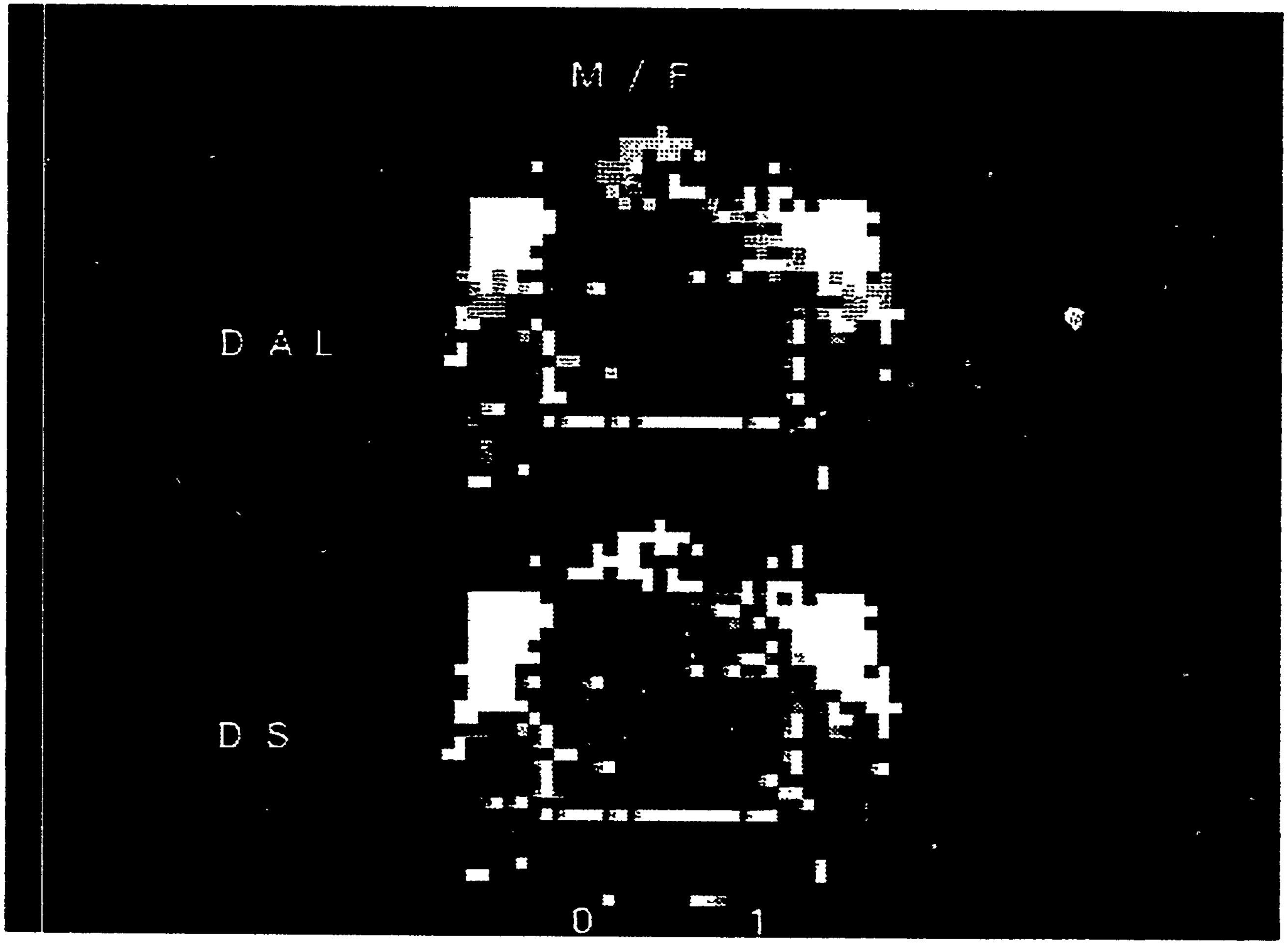


Figure B-10. DAL vs. DS mobility or firepower comparison

APPENDIX C

Sensitivity Excursions

INTENTIONALLY LEFT BLANK.

The following bar charts show the sensitivity of the two methodologies (DAL and DS) to range, dispersion, exposure, threat and azimuth. The DAL LOF values given a hit are the traditional M/F metrics. The DS values represent the probability of some kill definition (other than the "no damage" state) from either the mobility or firepower kill categories given a hit to the vehicle.

INTENTIONALLY LEFT BLANK.

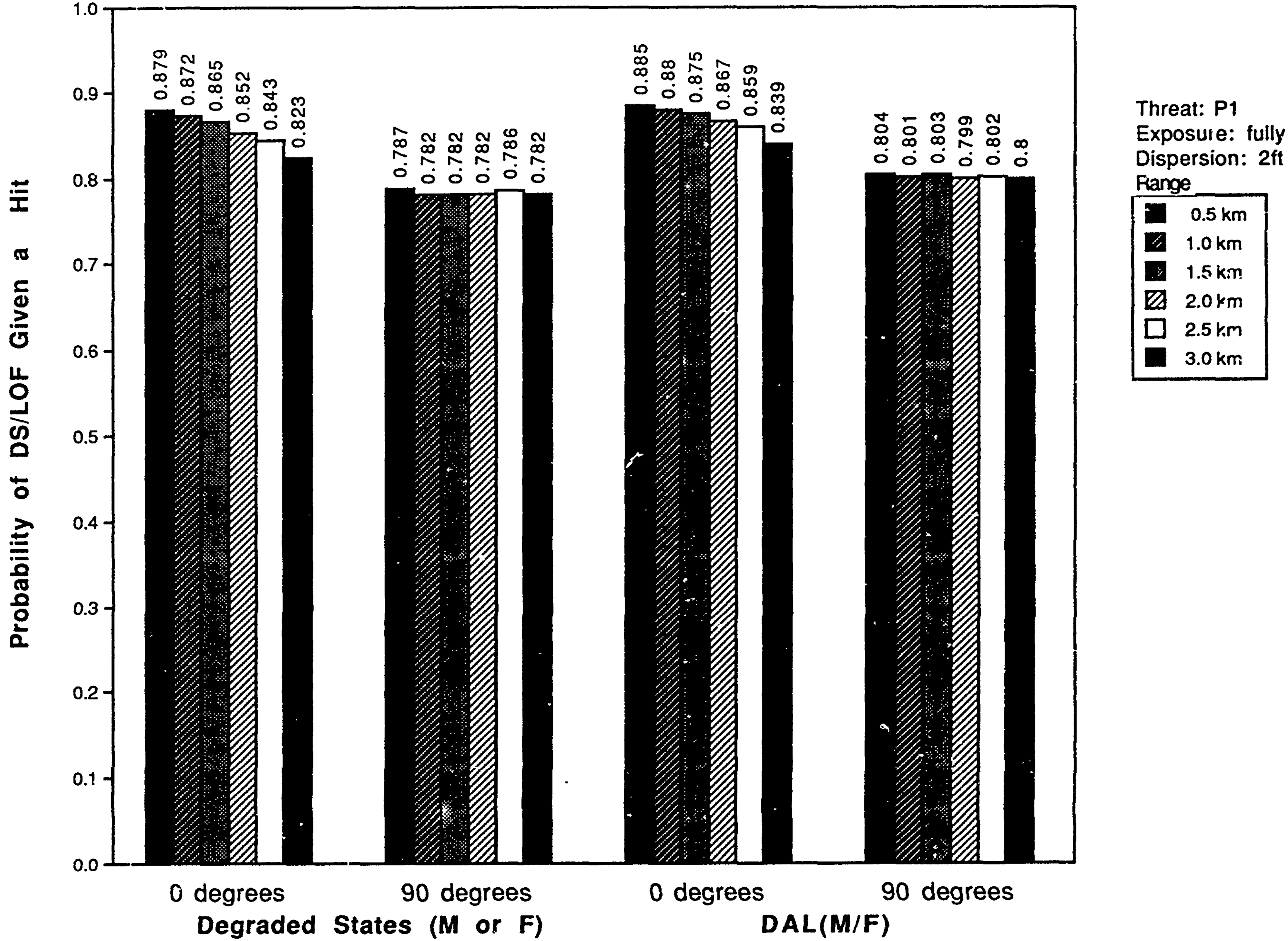


Figure C-1. Degraded States and DAL Range Sensitivity

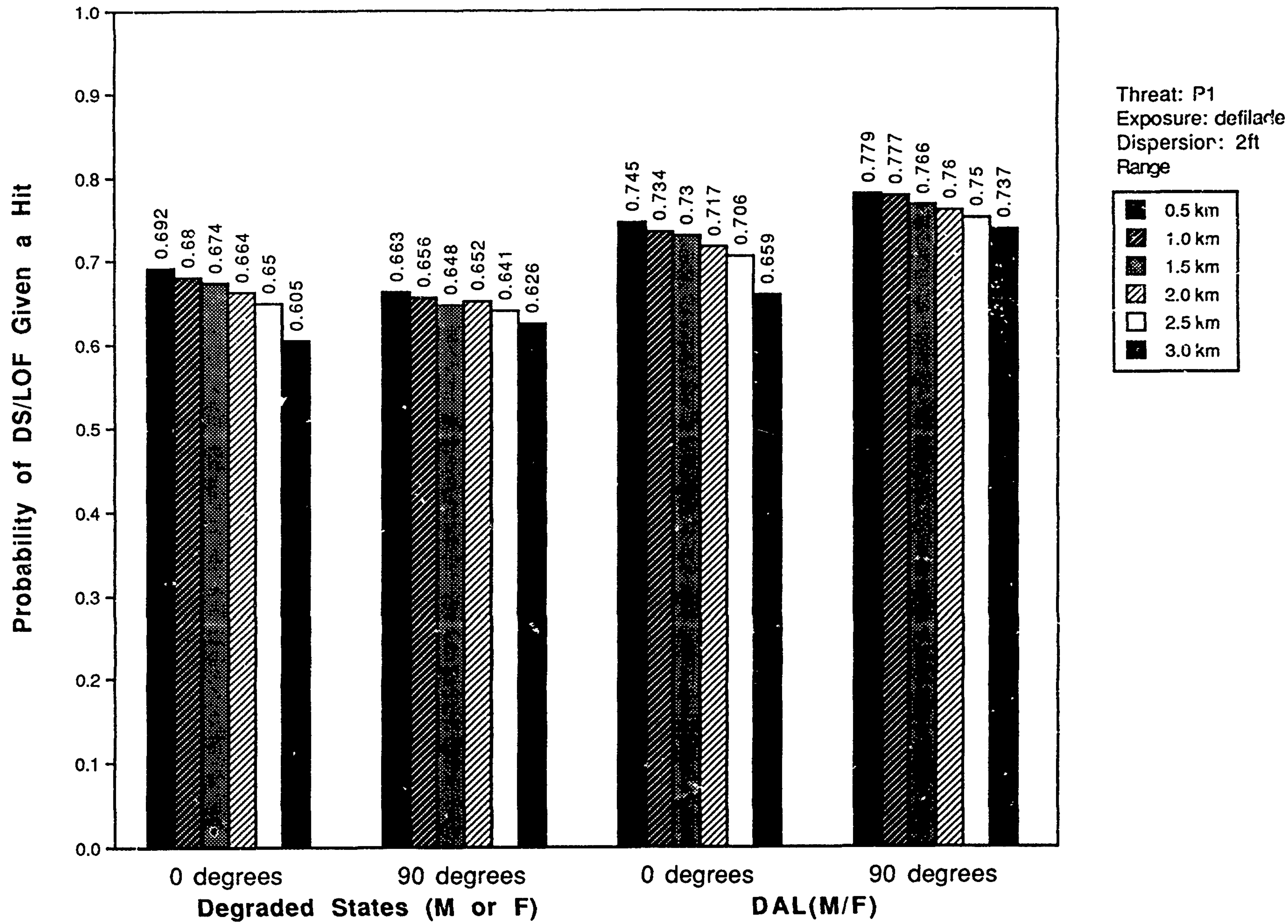


Figure C-2. Degraded States and DAL Range Sensitivity

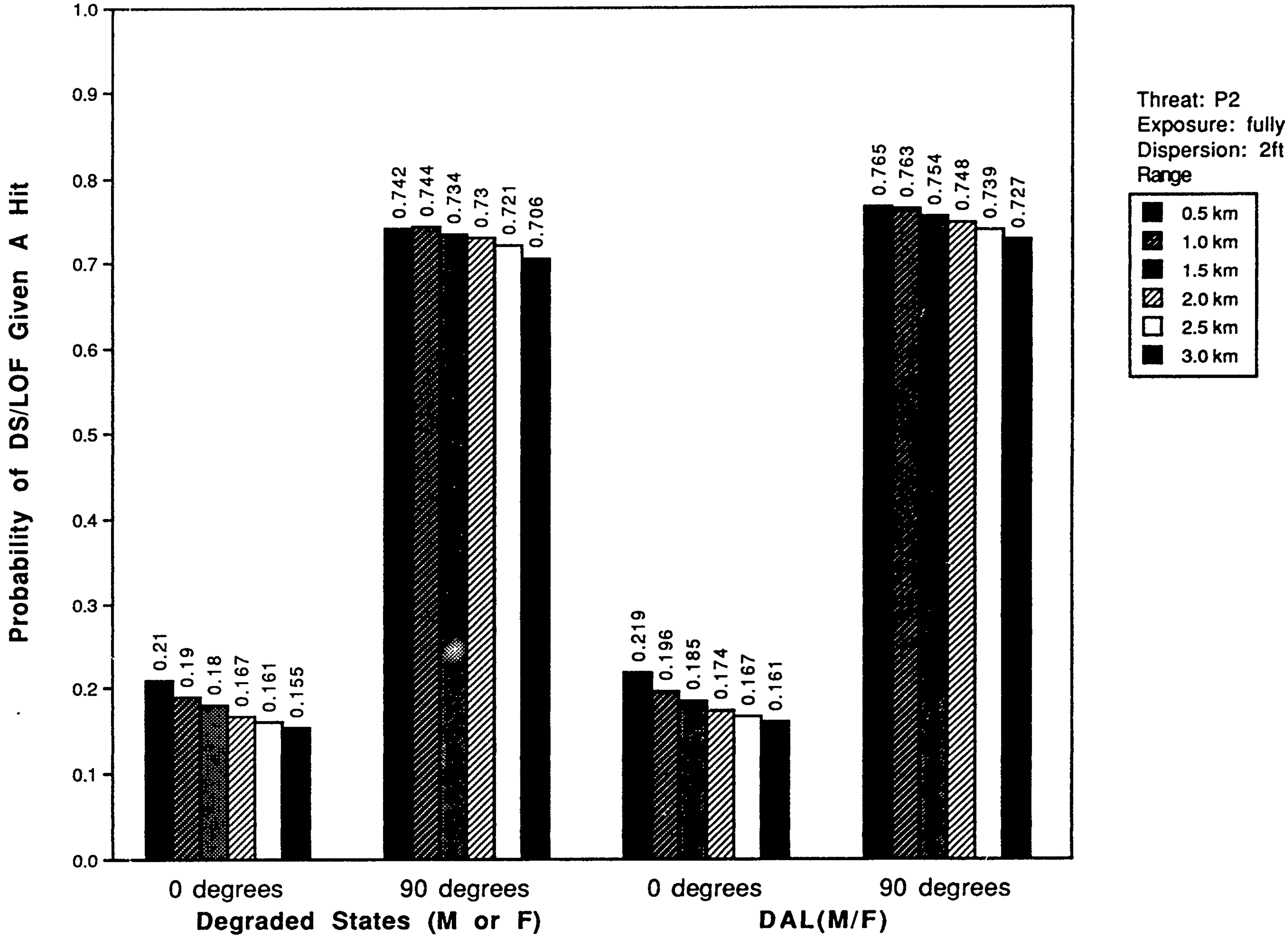


Figure C-3. Degraded States and DAL Range Sensitivity

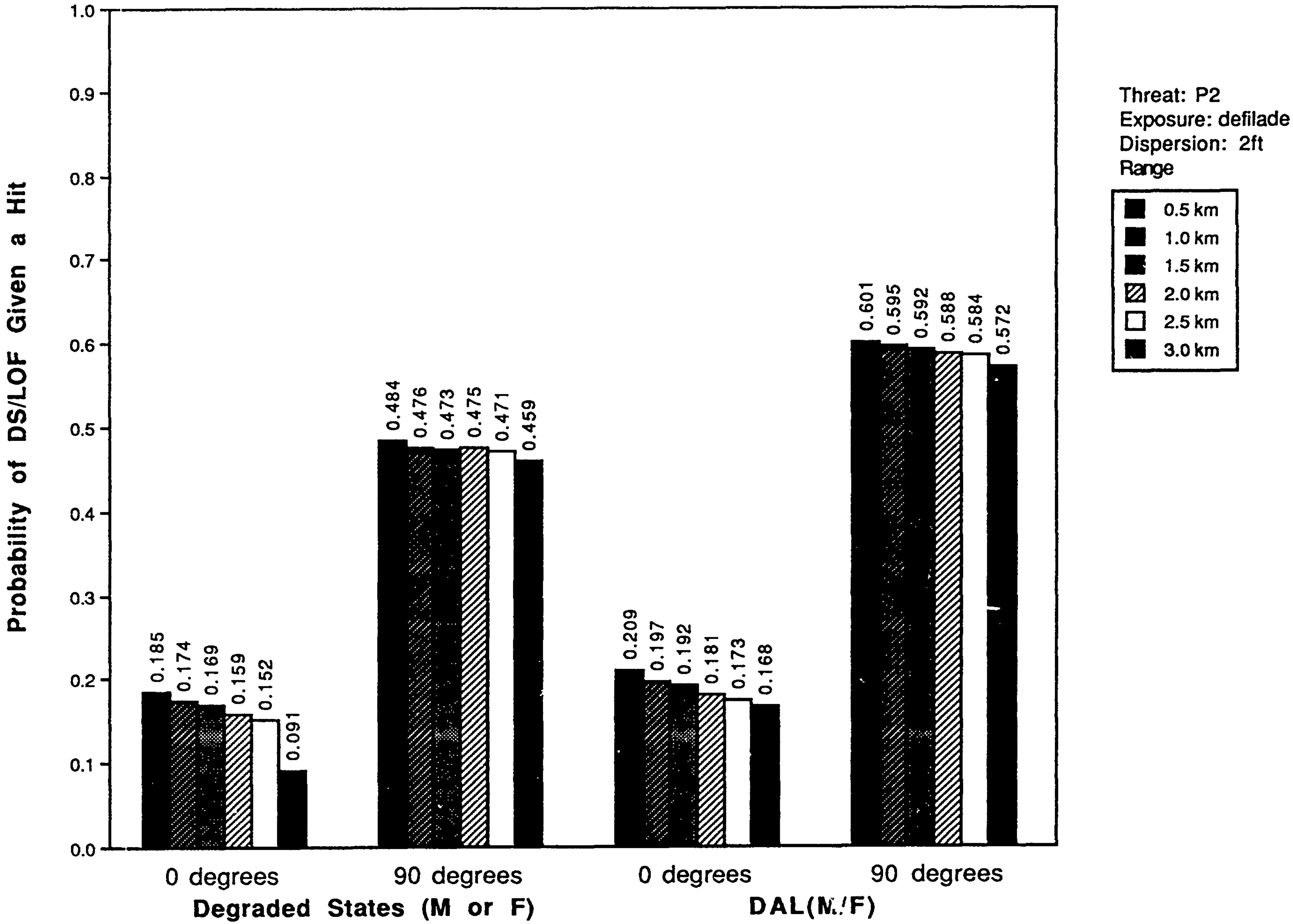


Figure C-4. Degraded States and DAL Range Sensitivity

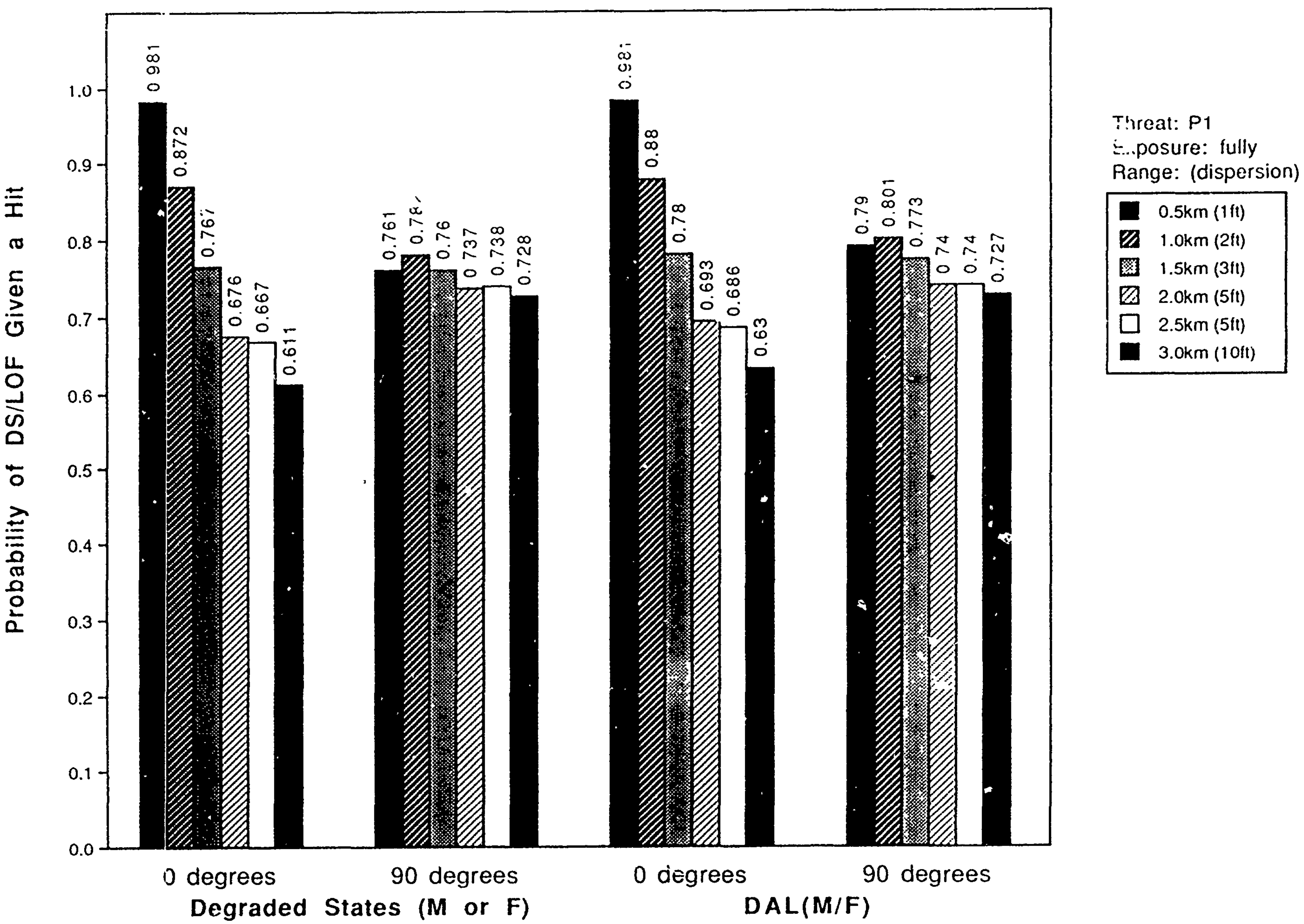


Figure C-5. Degraded States and DAL Range Sensitivity

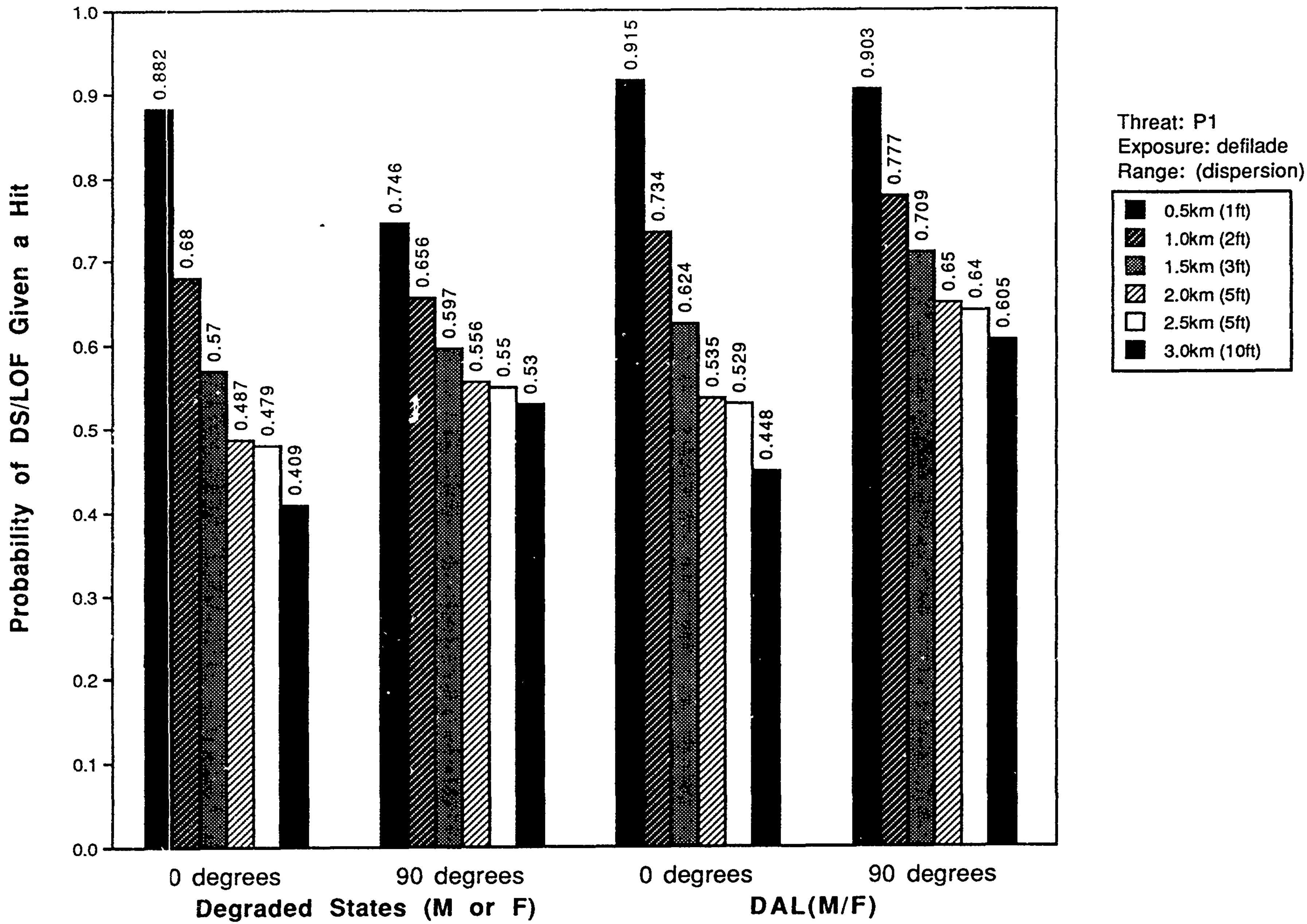


Figure C-6. Degraded States and DAL Range Sensitivity

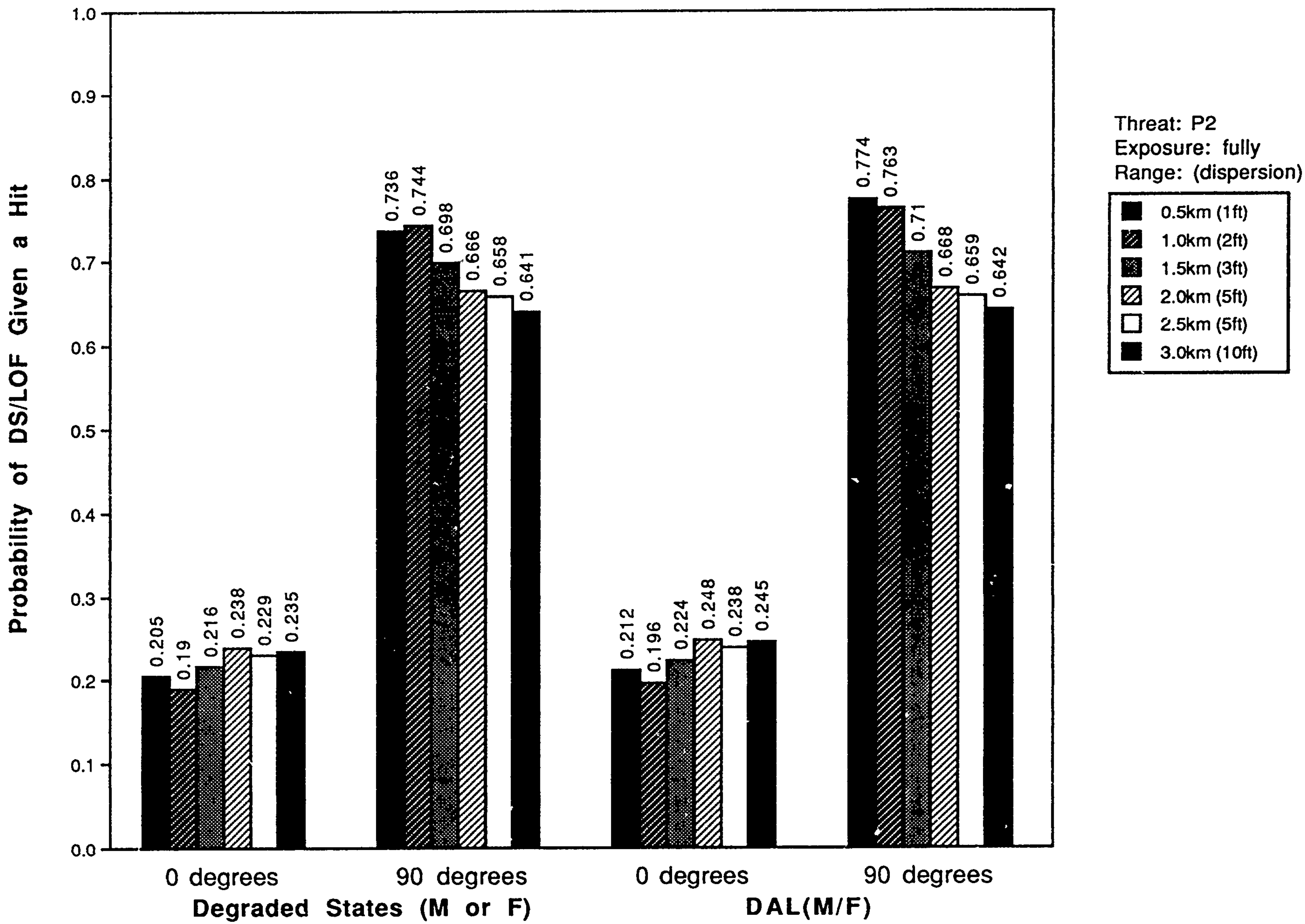


Figure C-7. Degraded States and DAL Range Sensitivity

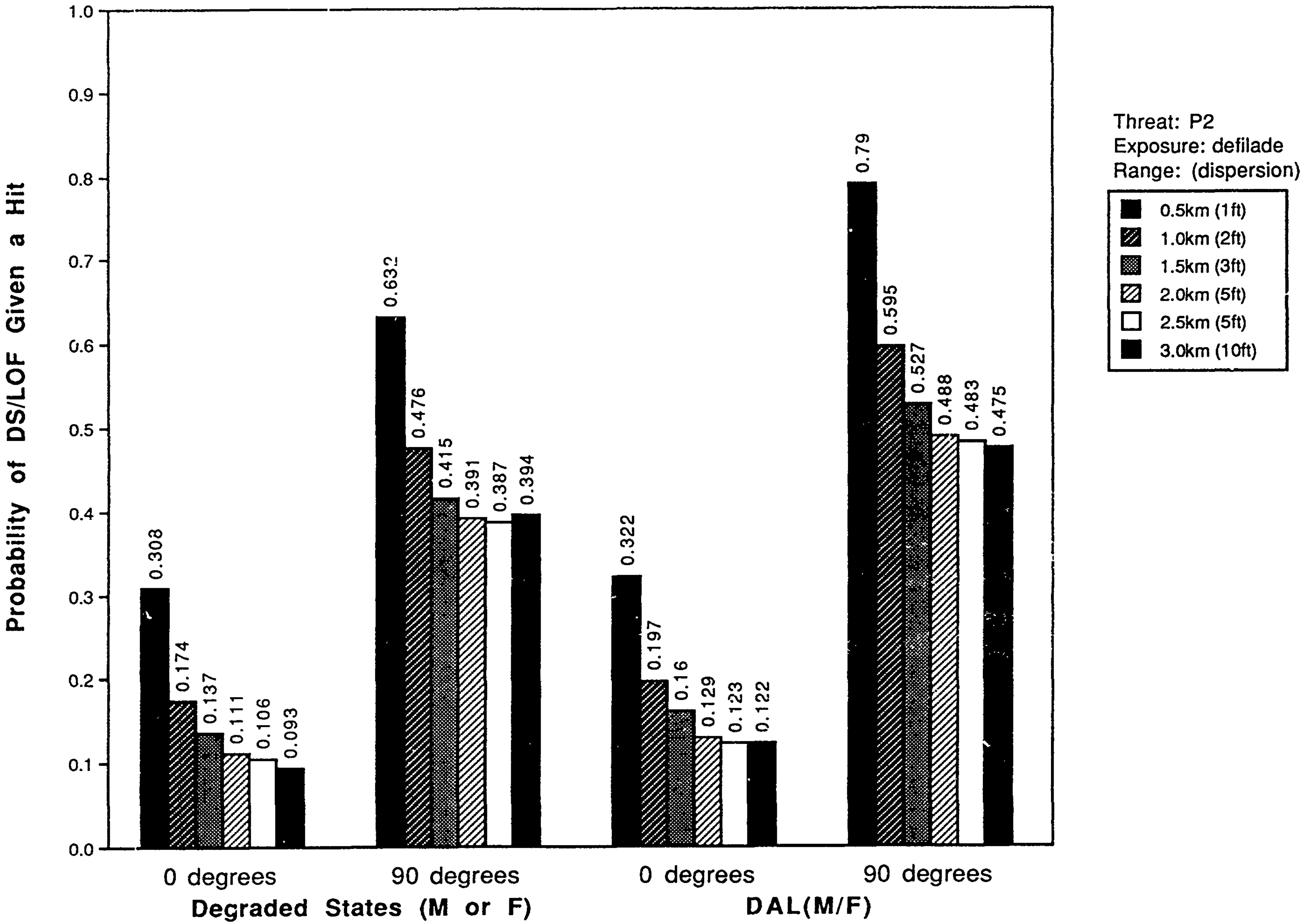


Figure C-8. Degraded States and DAL Range Sensitivity

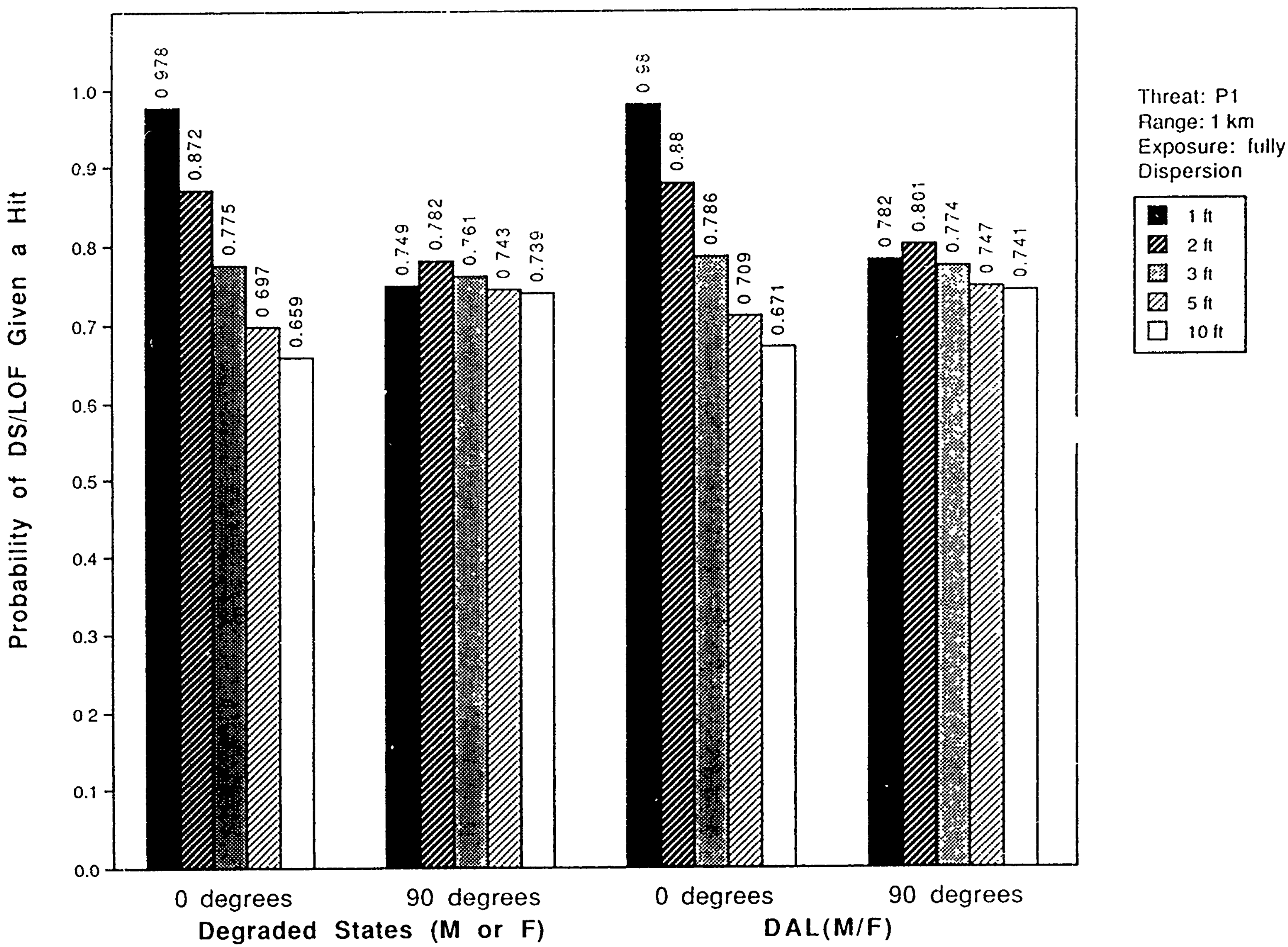


Figure C-9. Degraded States and DAL Dispersion Sensitivity

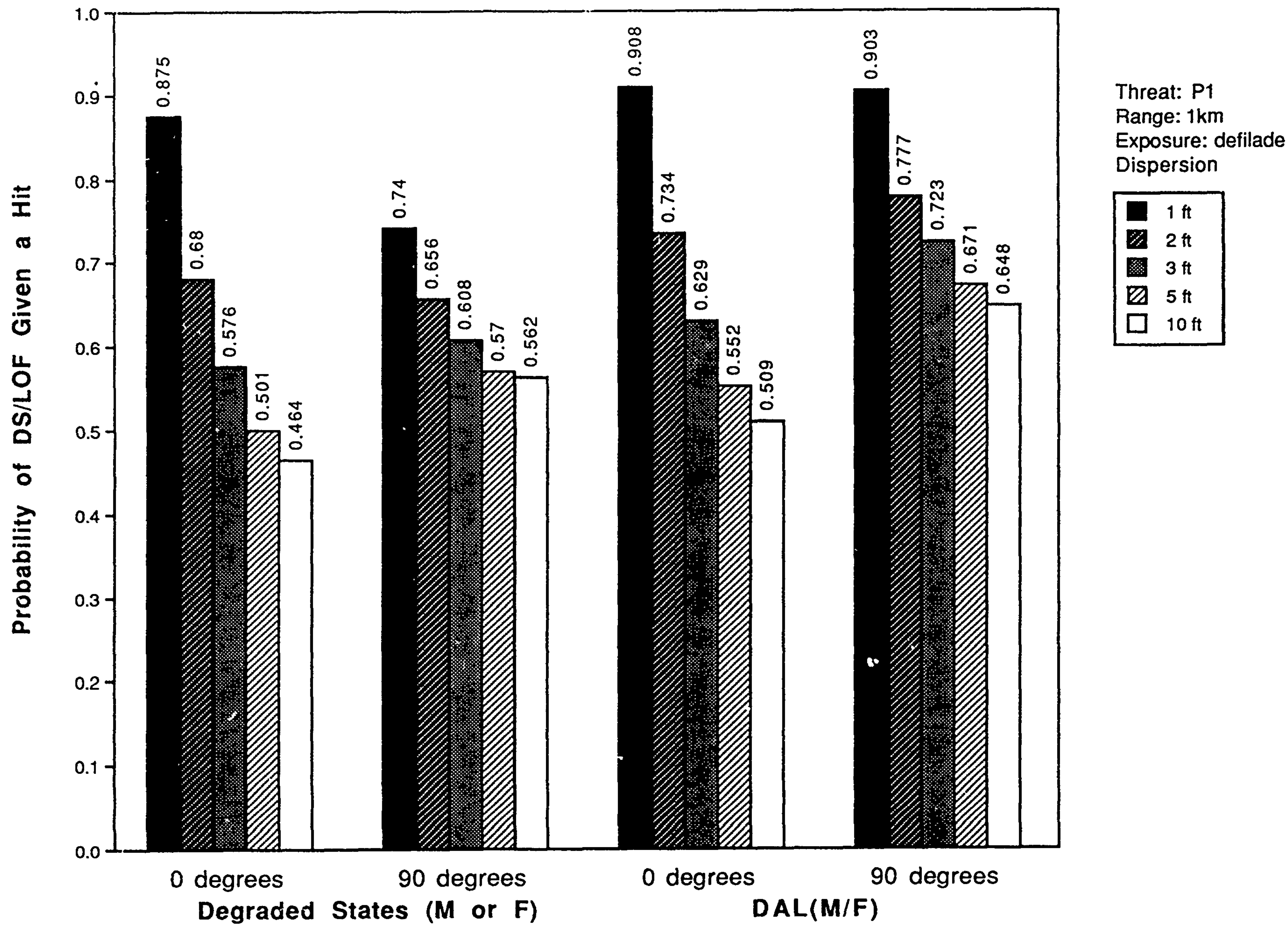


Figure C-10. Degraded States and DAL Dispersion Sensitivity

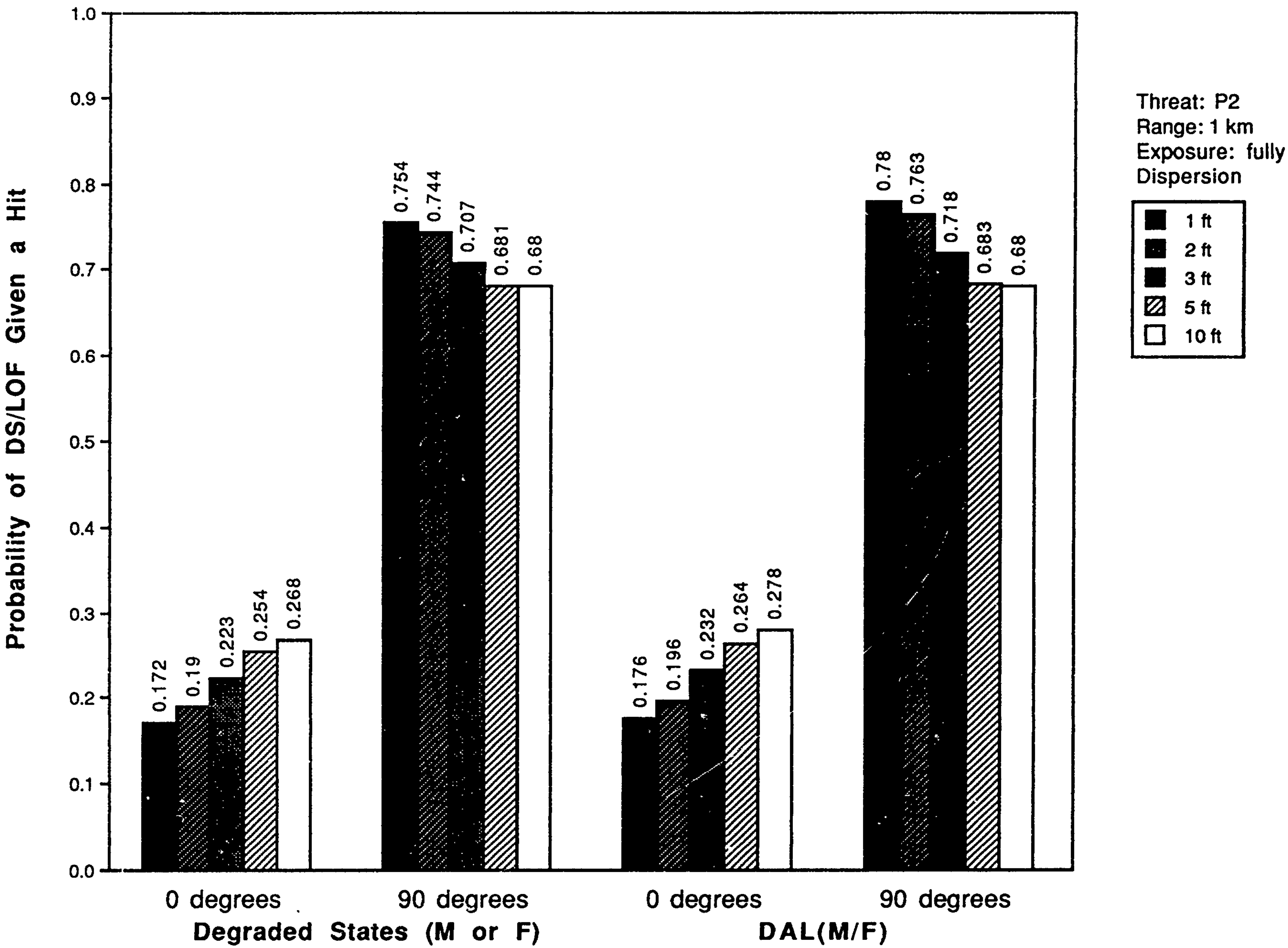


Figure C-11. Degraded States and DAL Dispersion Sensitivity

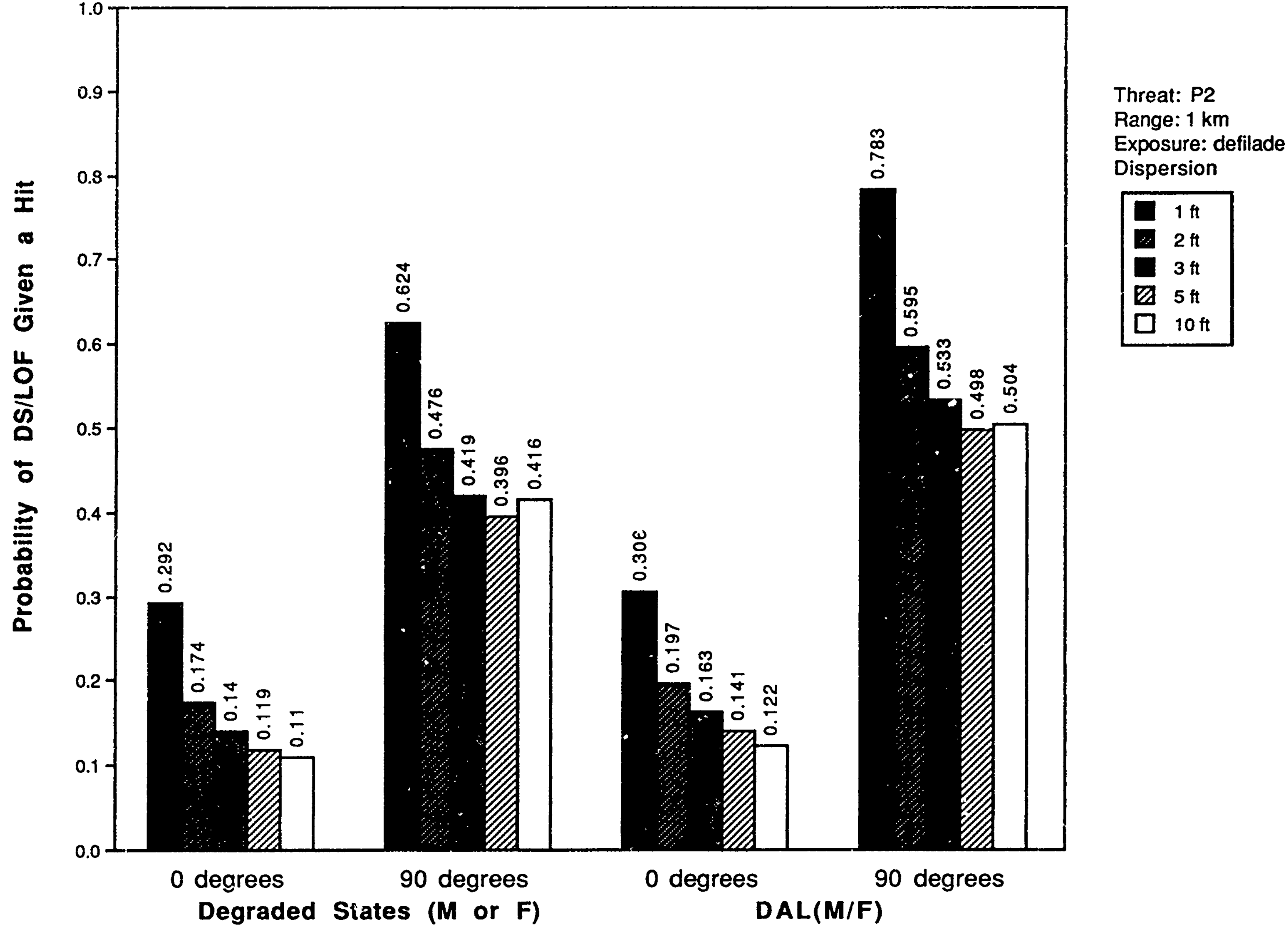


Figure C-12. Degraded States and DAL Dispersion Sensitivity

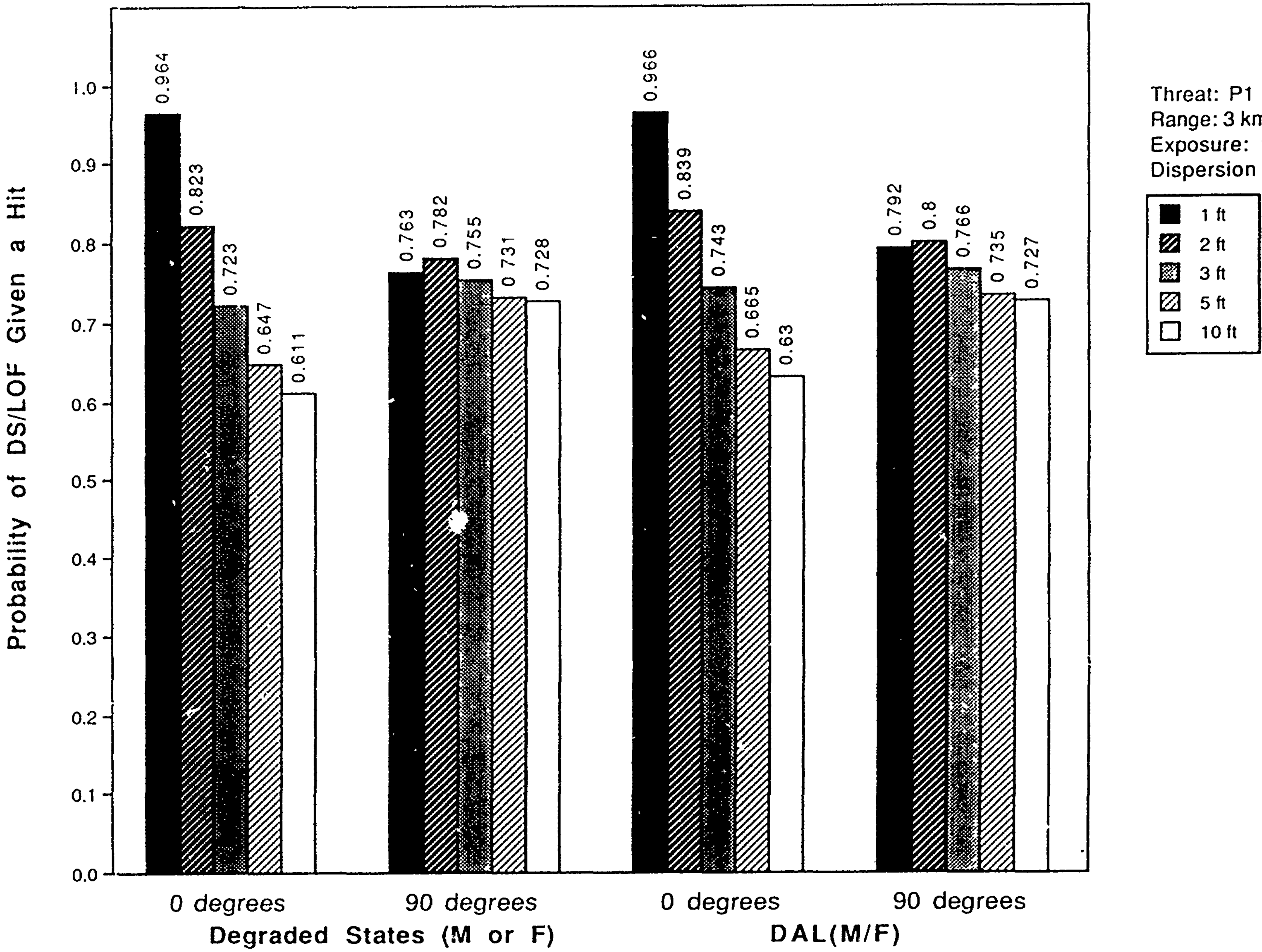


Figure C-13. Degraded States and DAL Dispersion Sensitivity

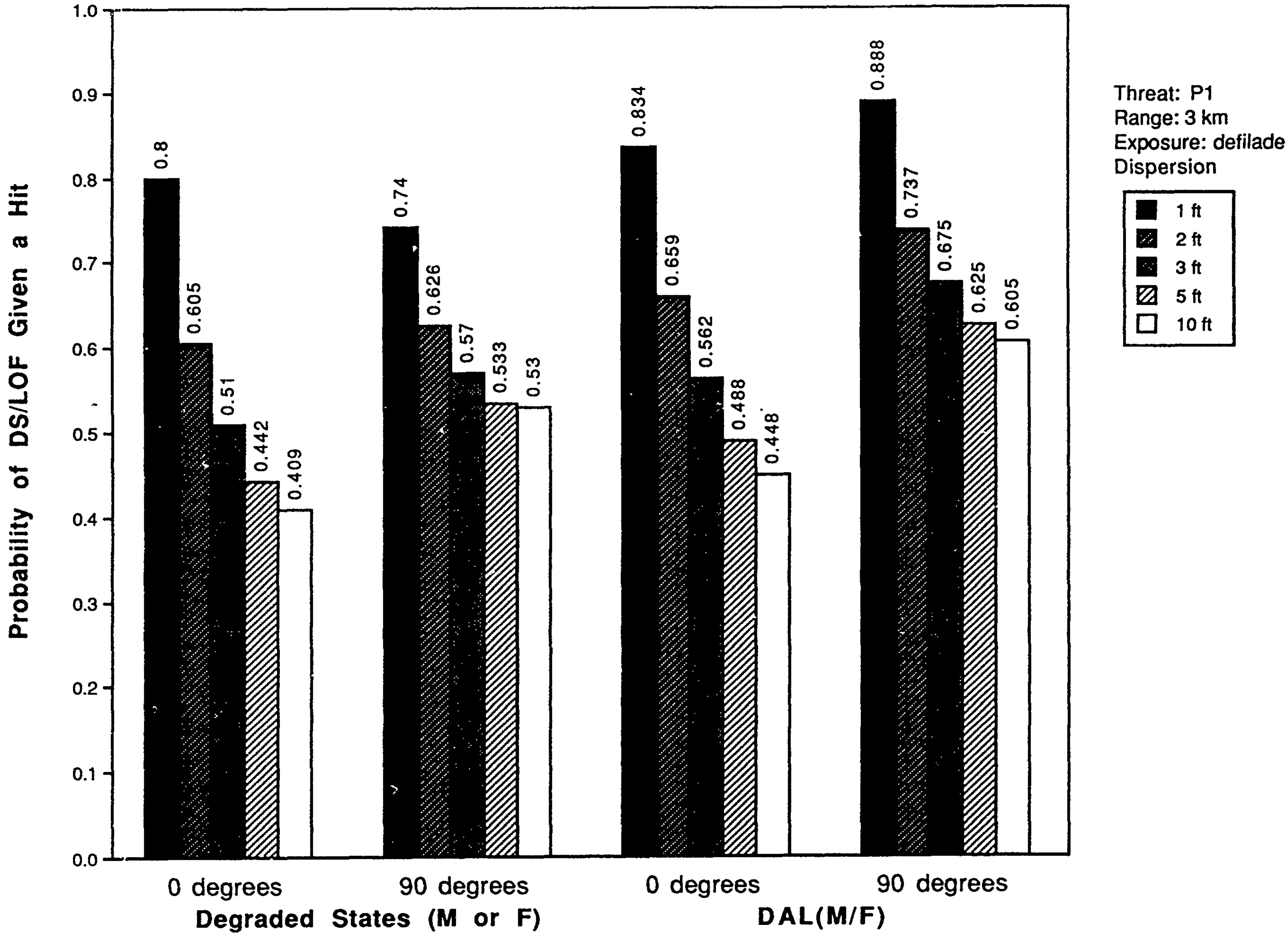


Figure C-14. Degraded States and DAL Dispersion Sensitivity

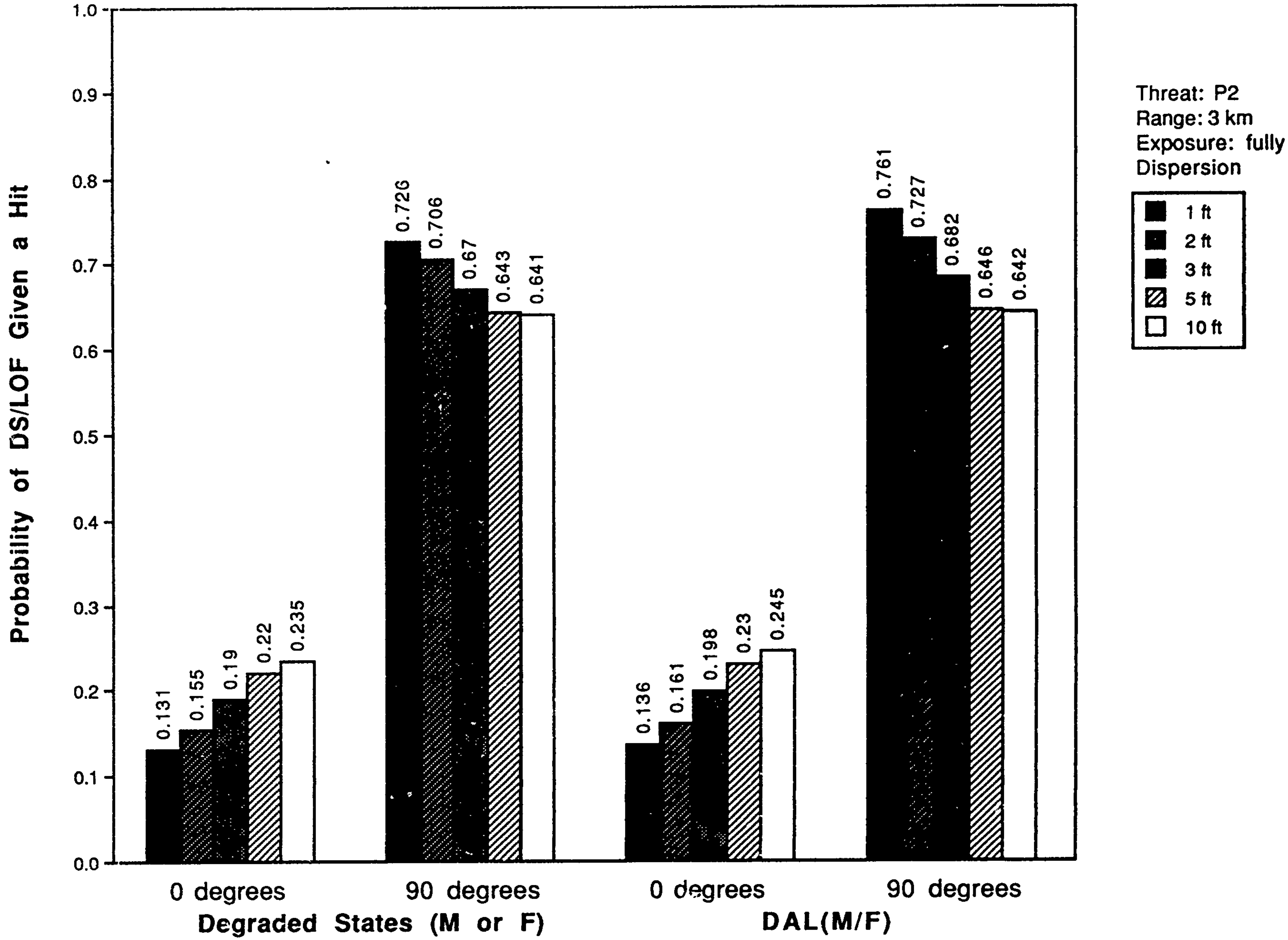


Figure C-15. Degraded States and DAL Dispersion Sensitivity

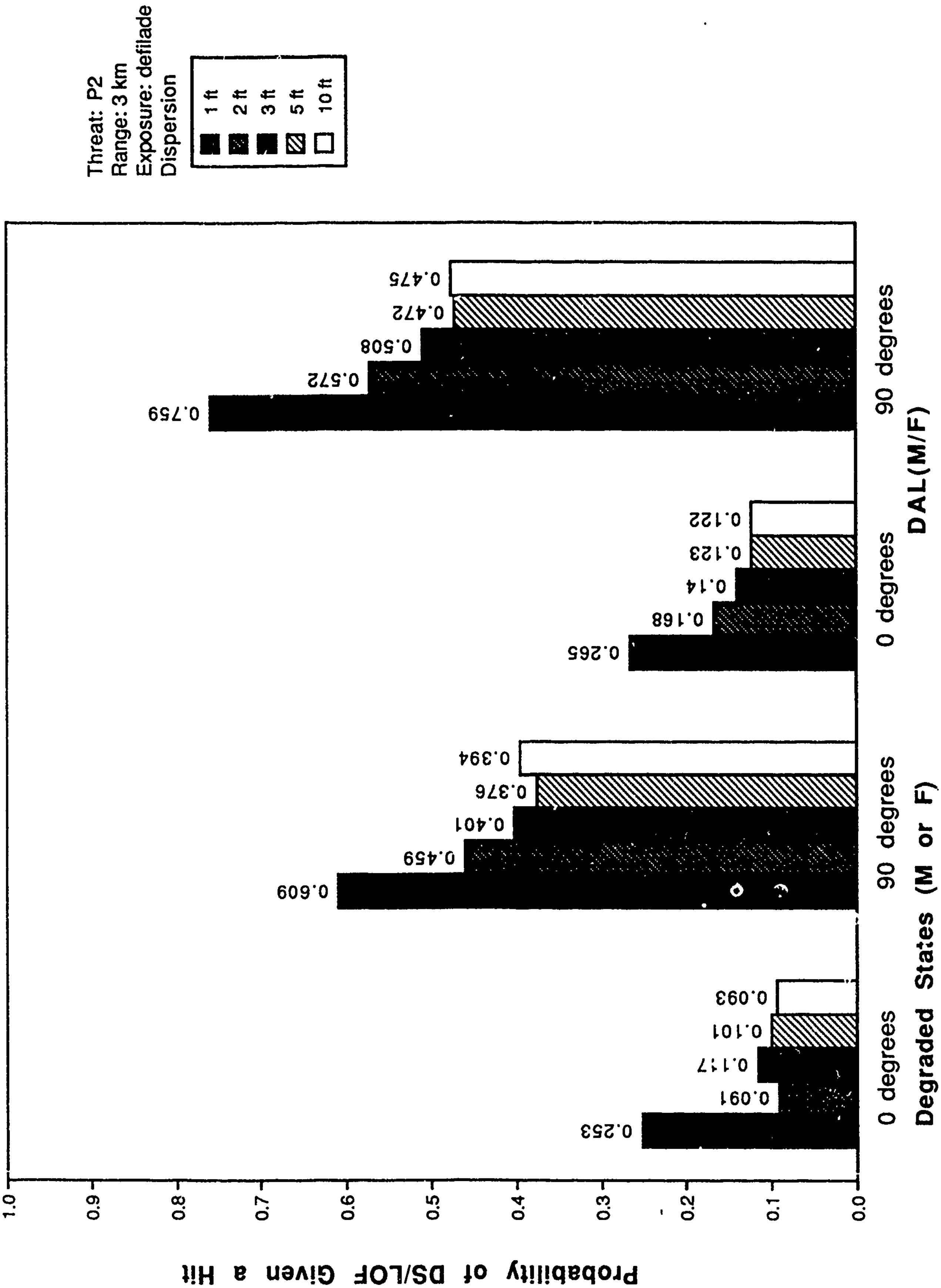


Figure C-16. Degraded States and DAL Dispersion Sensitivity

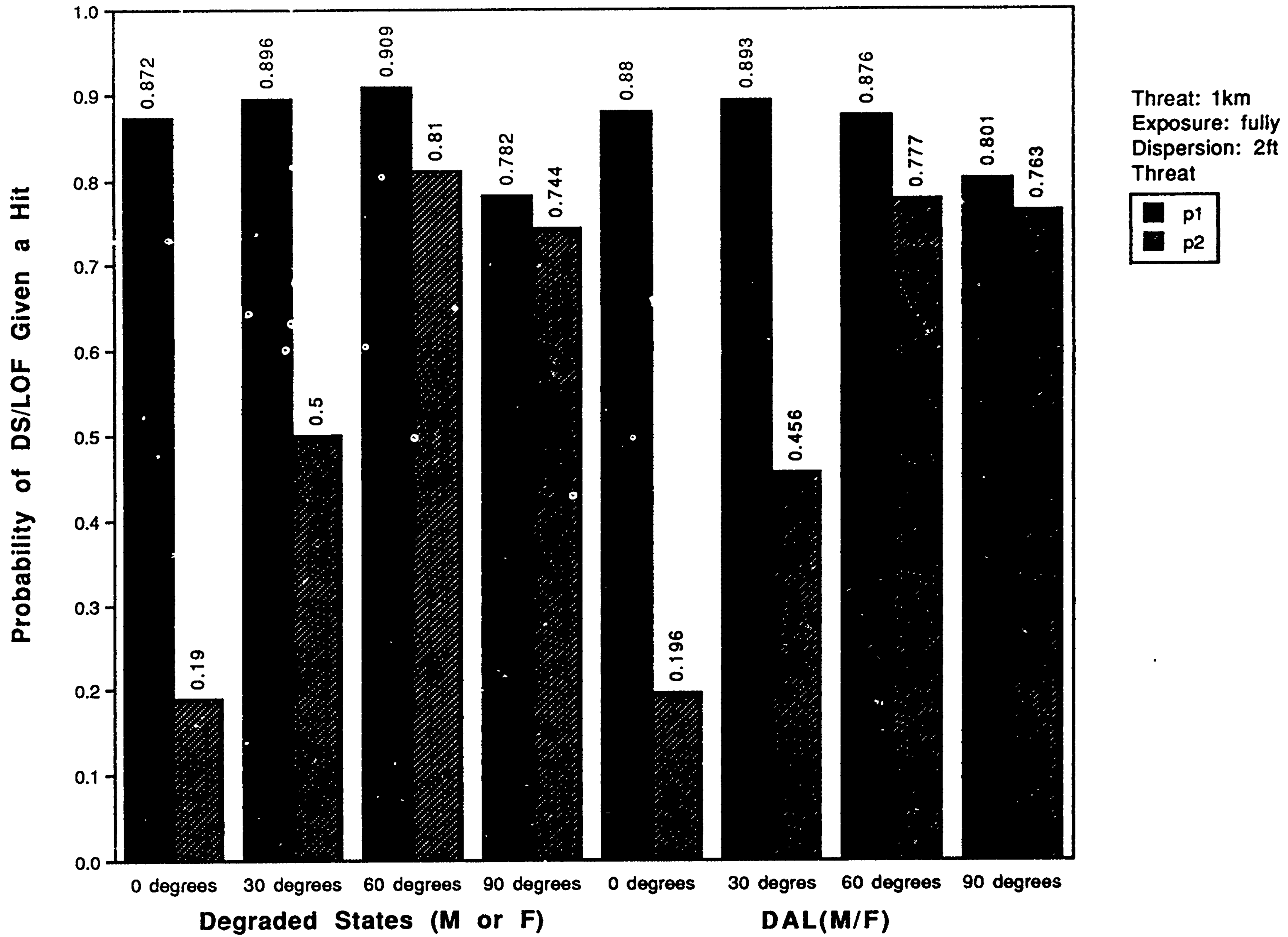


Figure C-17. Degraded States and DAL Threat Sensitivity

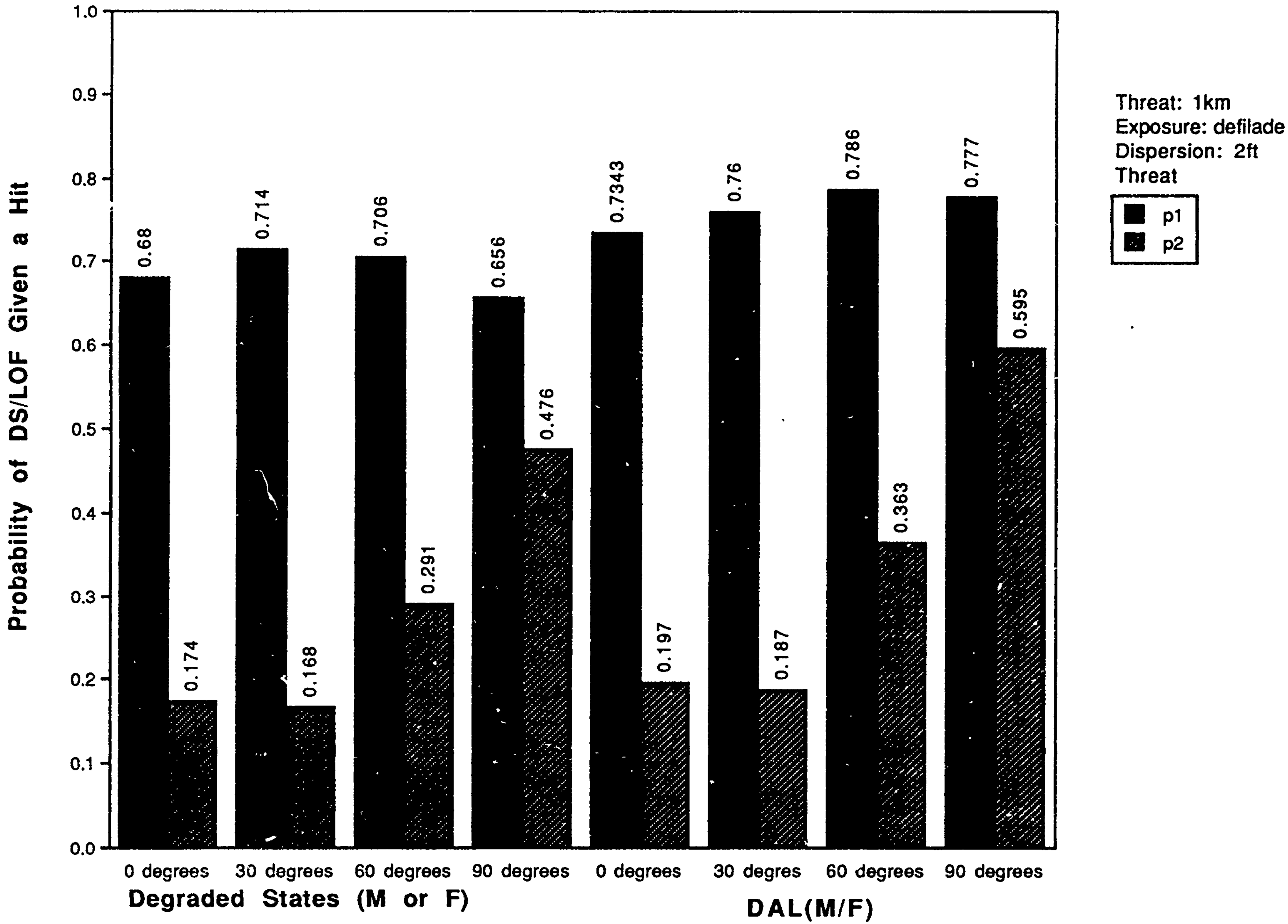


Figure C-18. Degraded States and DAL Threat Sensitivity

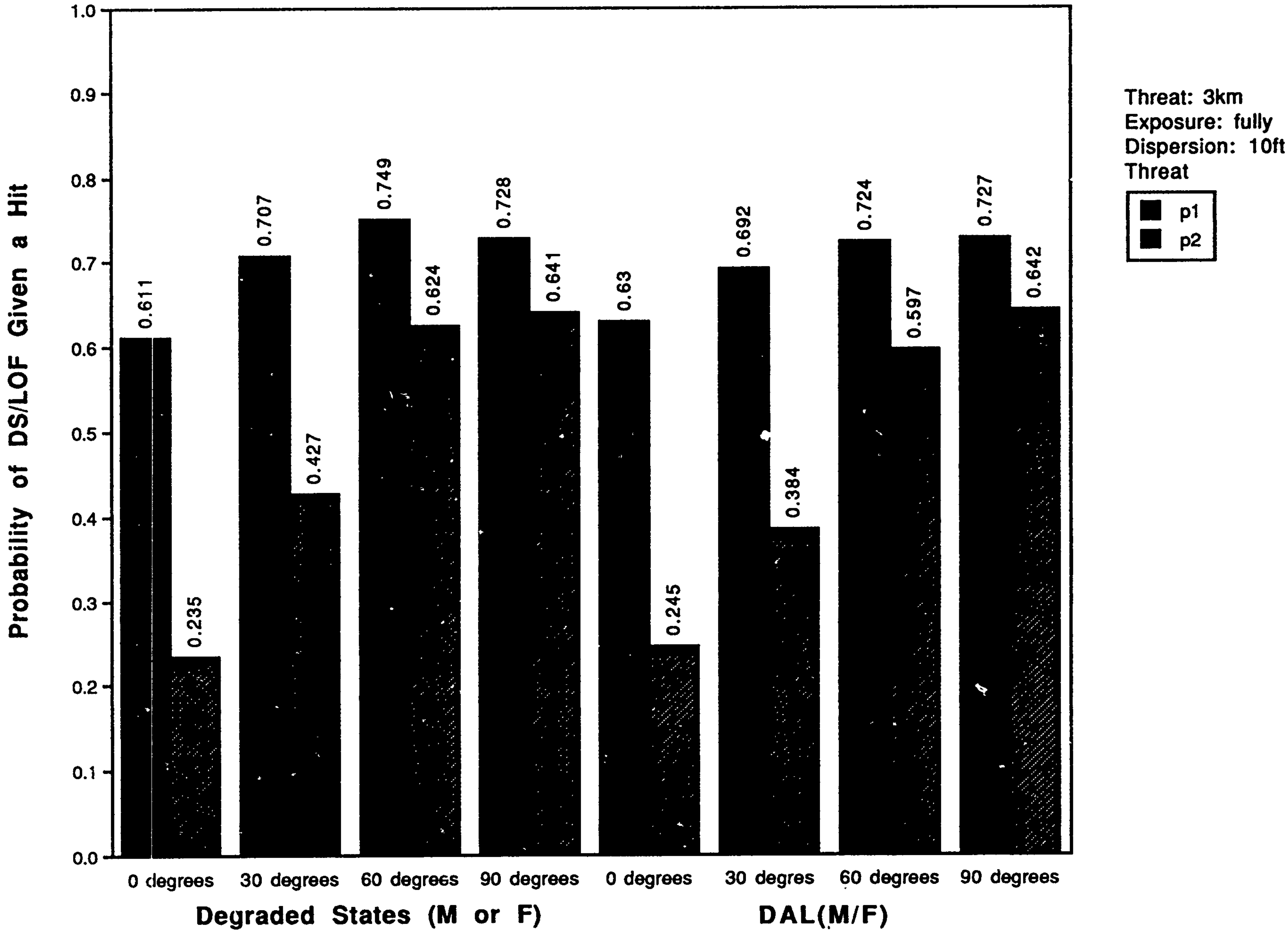


Figure C-19. Degraded States and DAL Threat Sensitivity

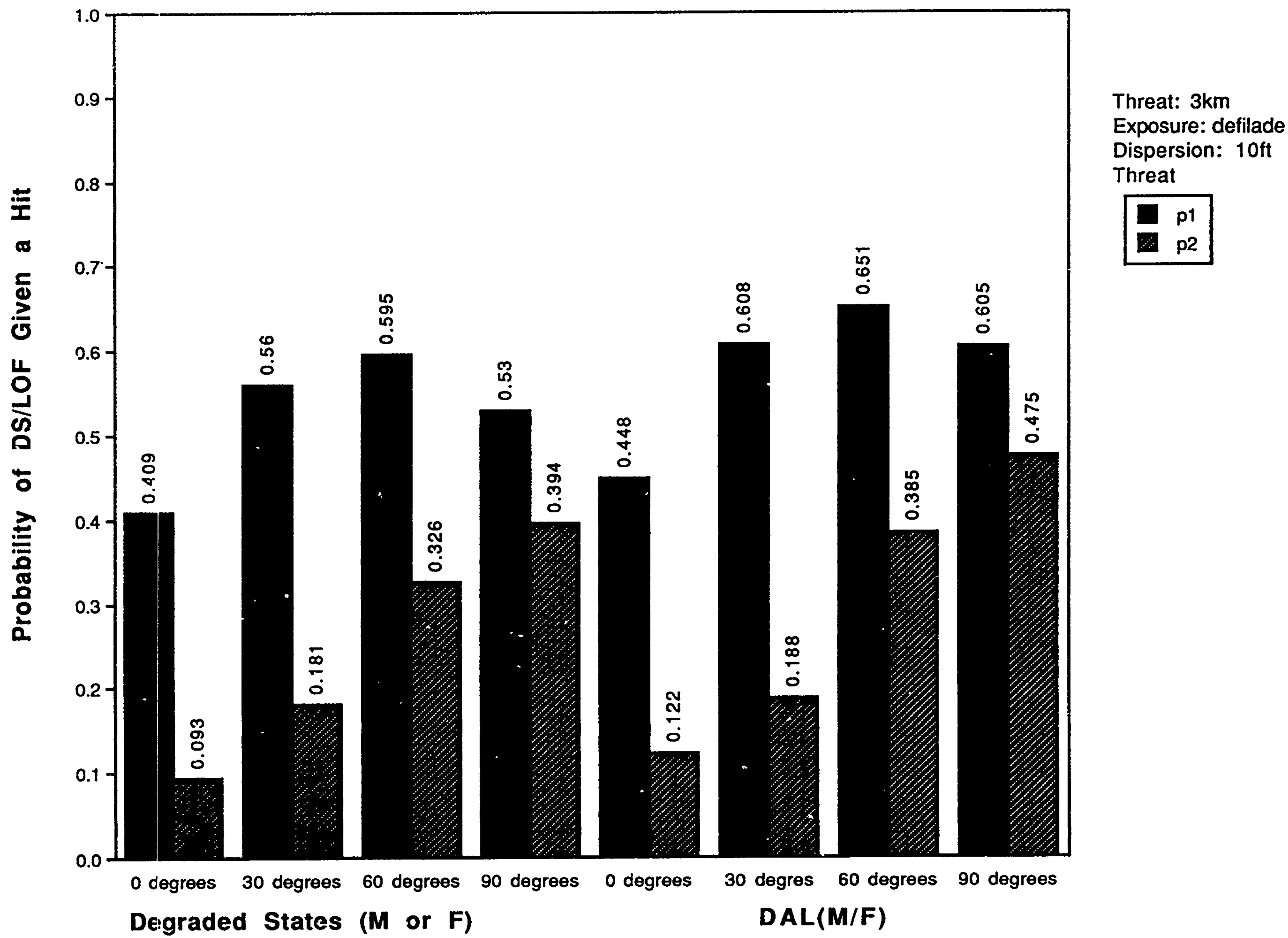


Figure C-20. Degraded States and DAL Threat Sensitivity

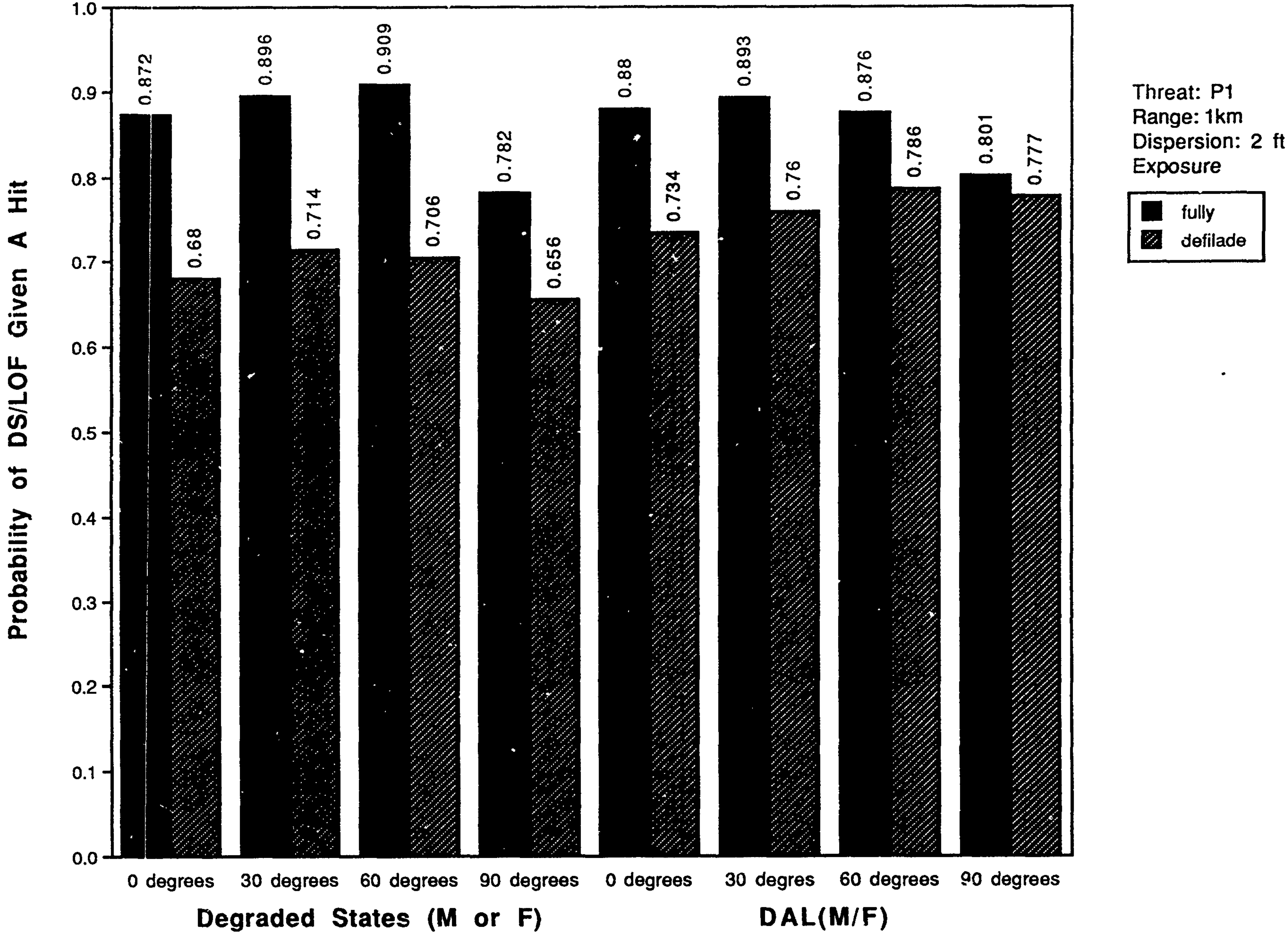


Figure C-21. Degraded States and DAL Exposure Sensitivity

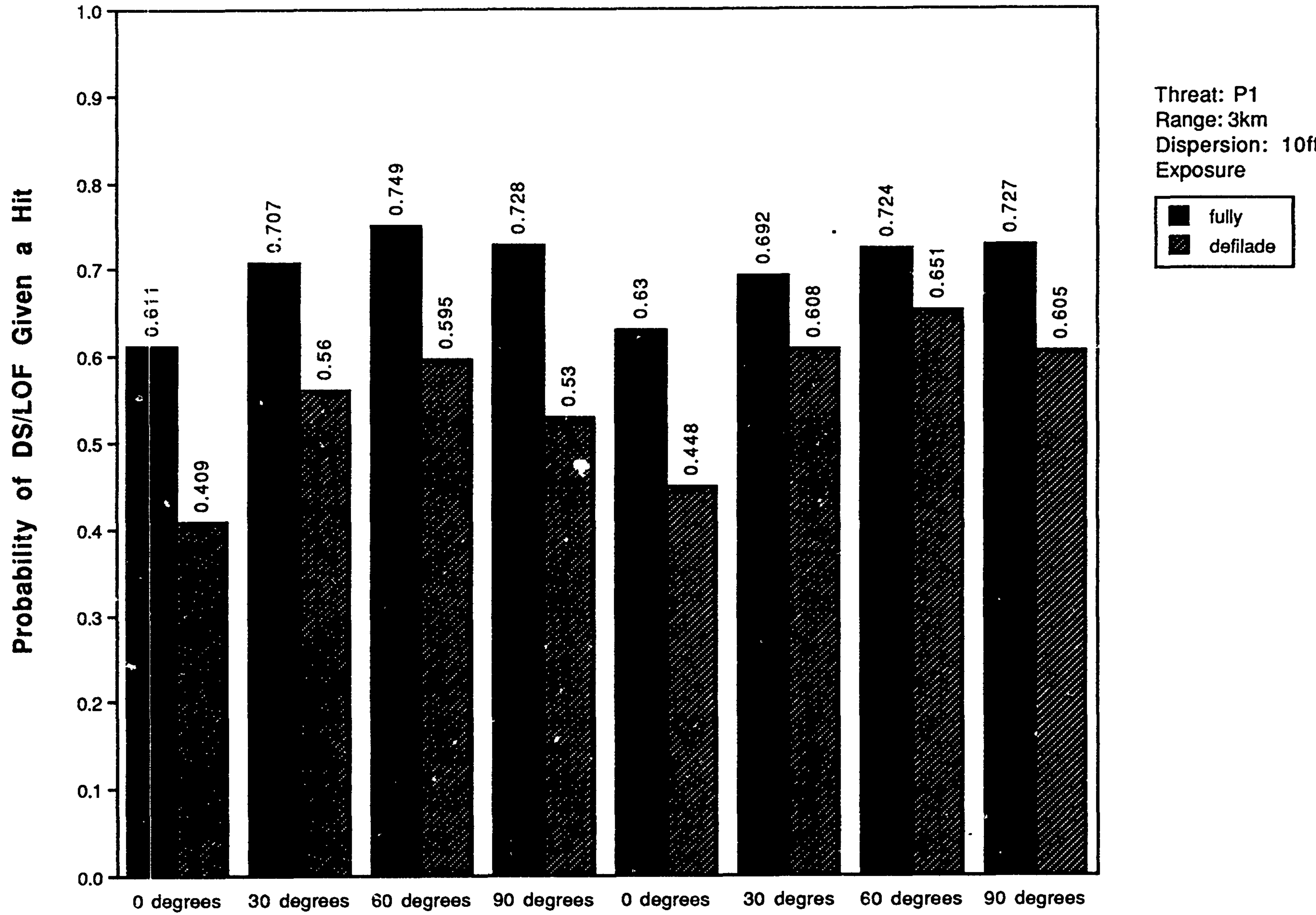


Figure C-22. Degraded States and DAL Exposure Sensitivity

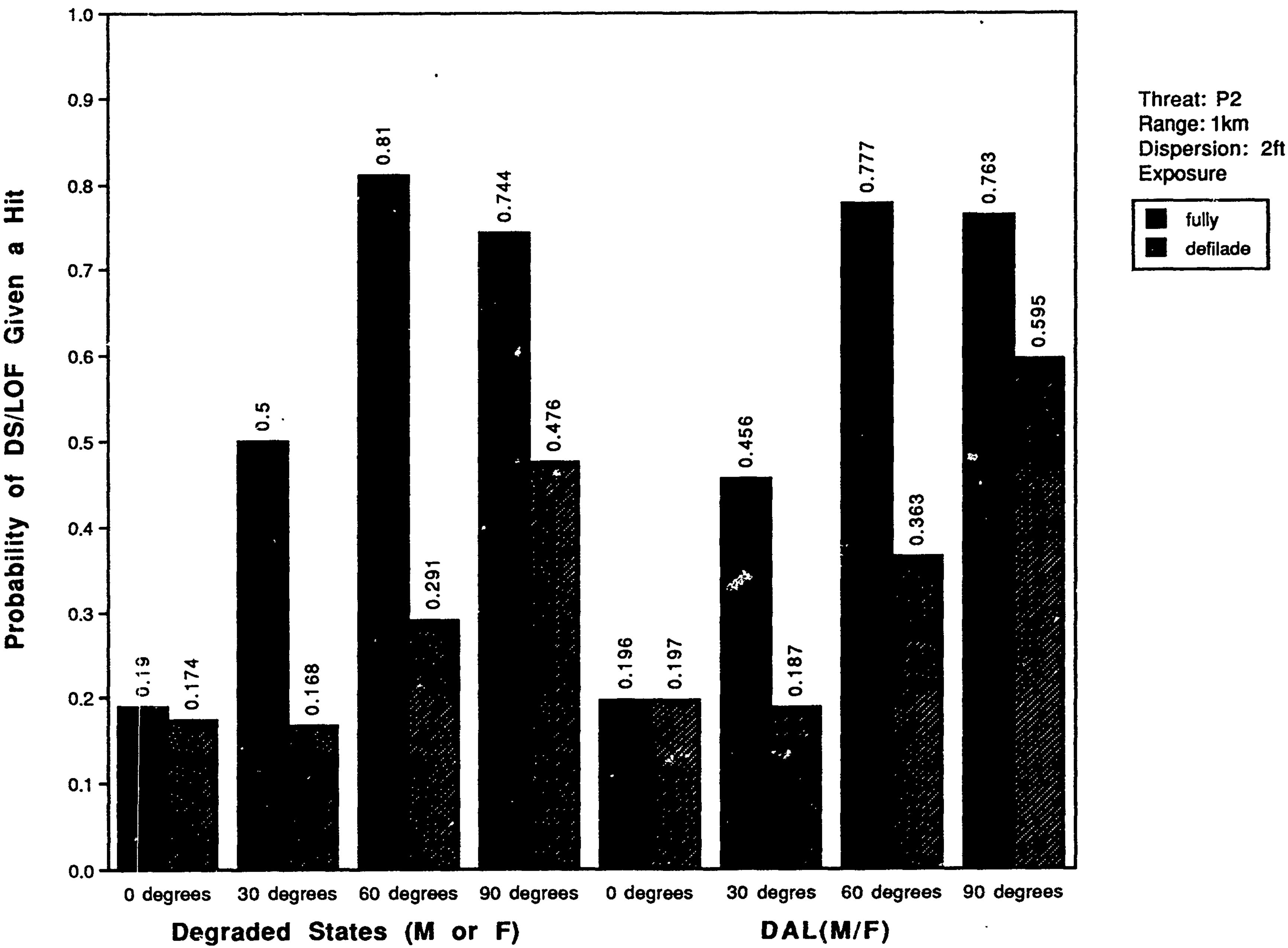


Figure C-23. Degraded States and DAL Exposure Sensitivity

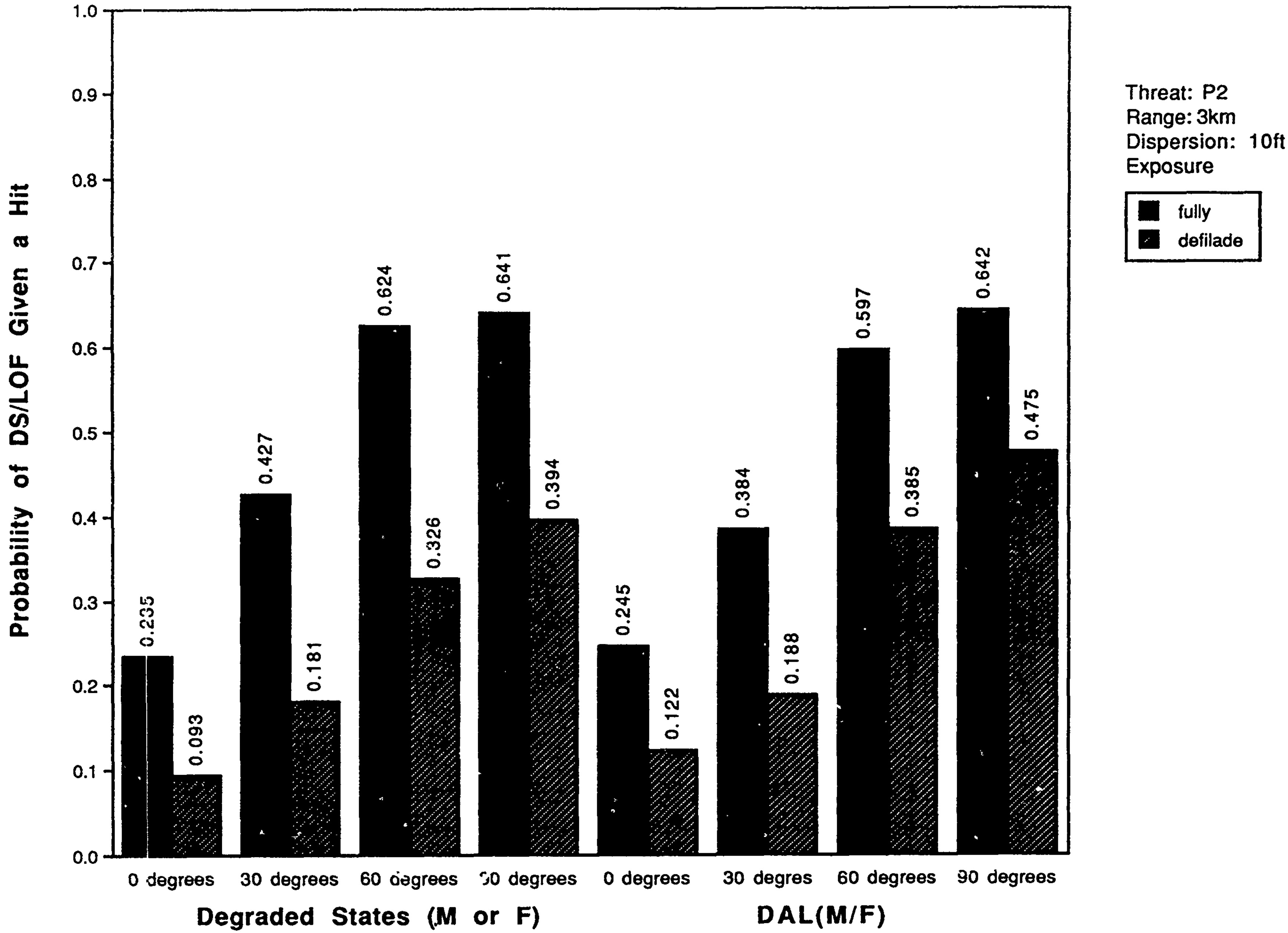


Figure C-24. Degraded States and DAL Exposure Sensitivity

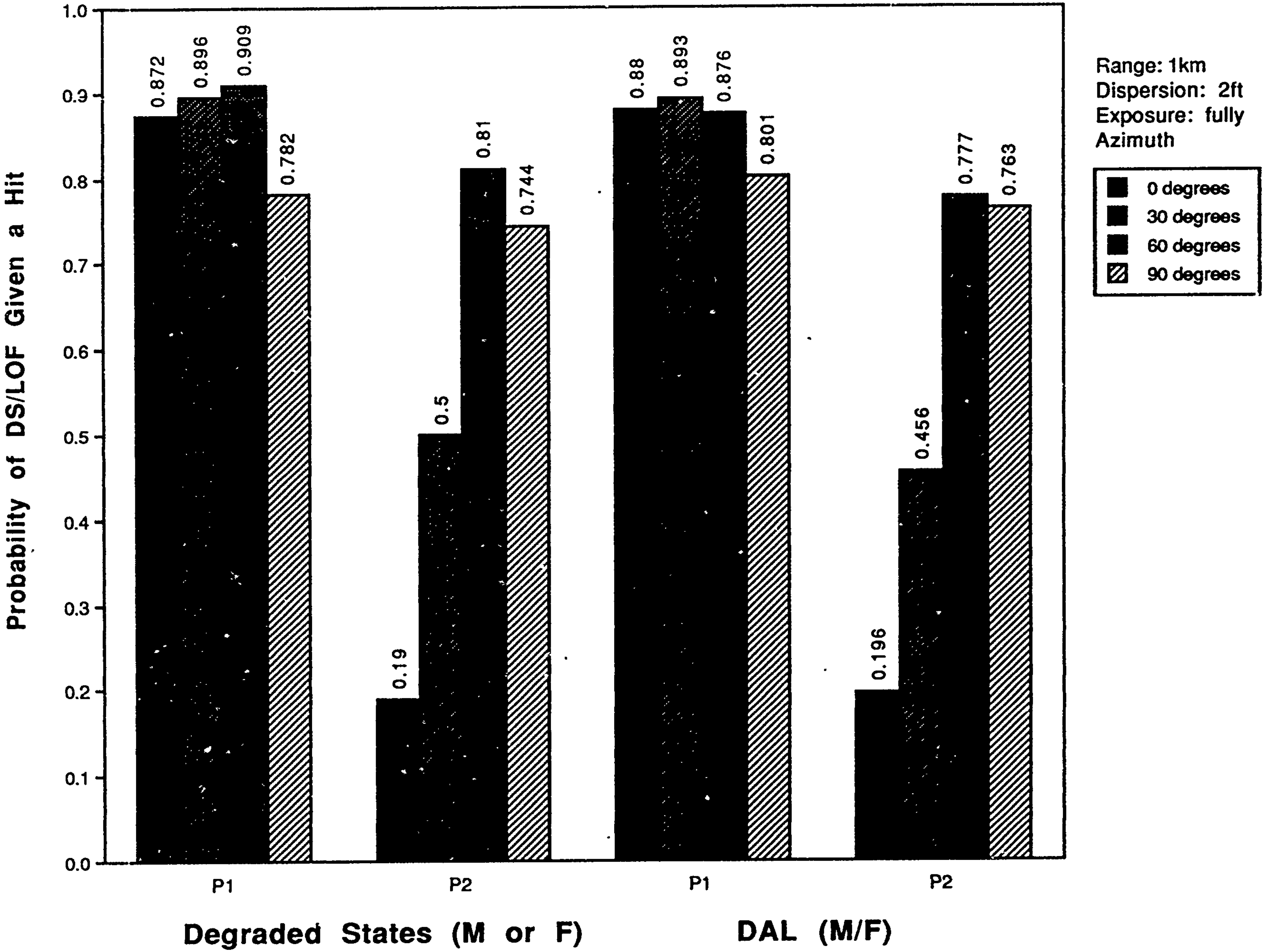


Figure C-25. Degraded States and DAL Azimuth Sensitivity

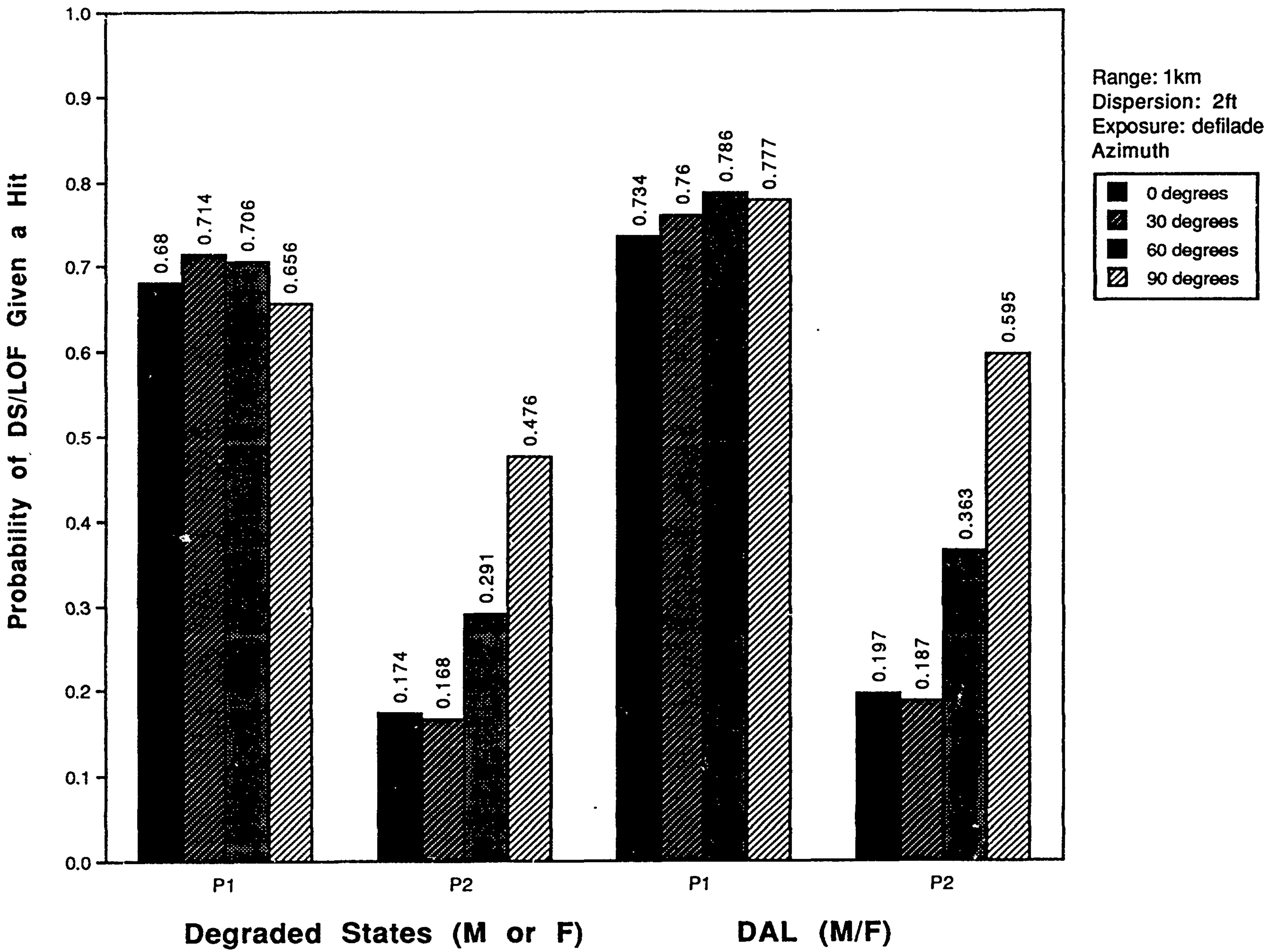


Figure C-26. Degraded States and DAL Azimuth Sensitivity

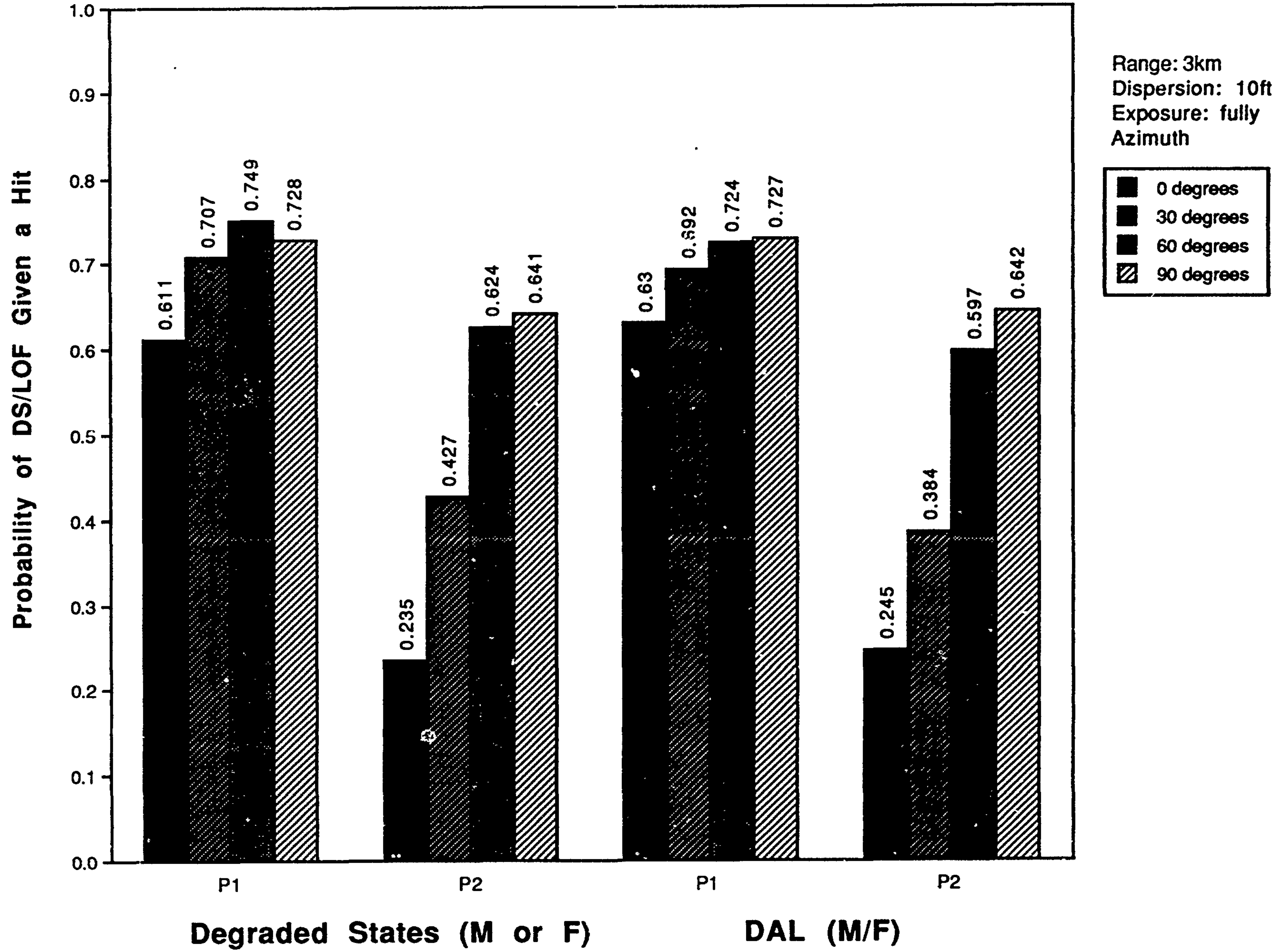


Figure C-27. Degraded States and DAL Azimuth Sensitivity

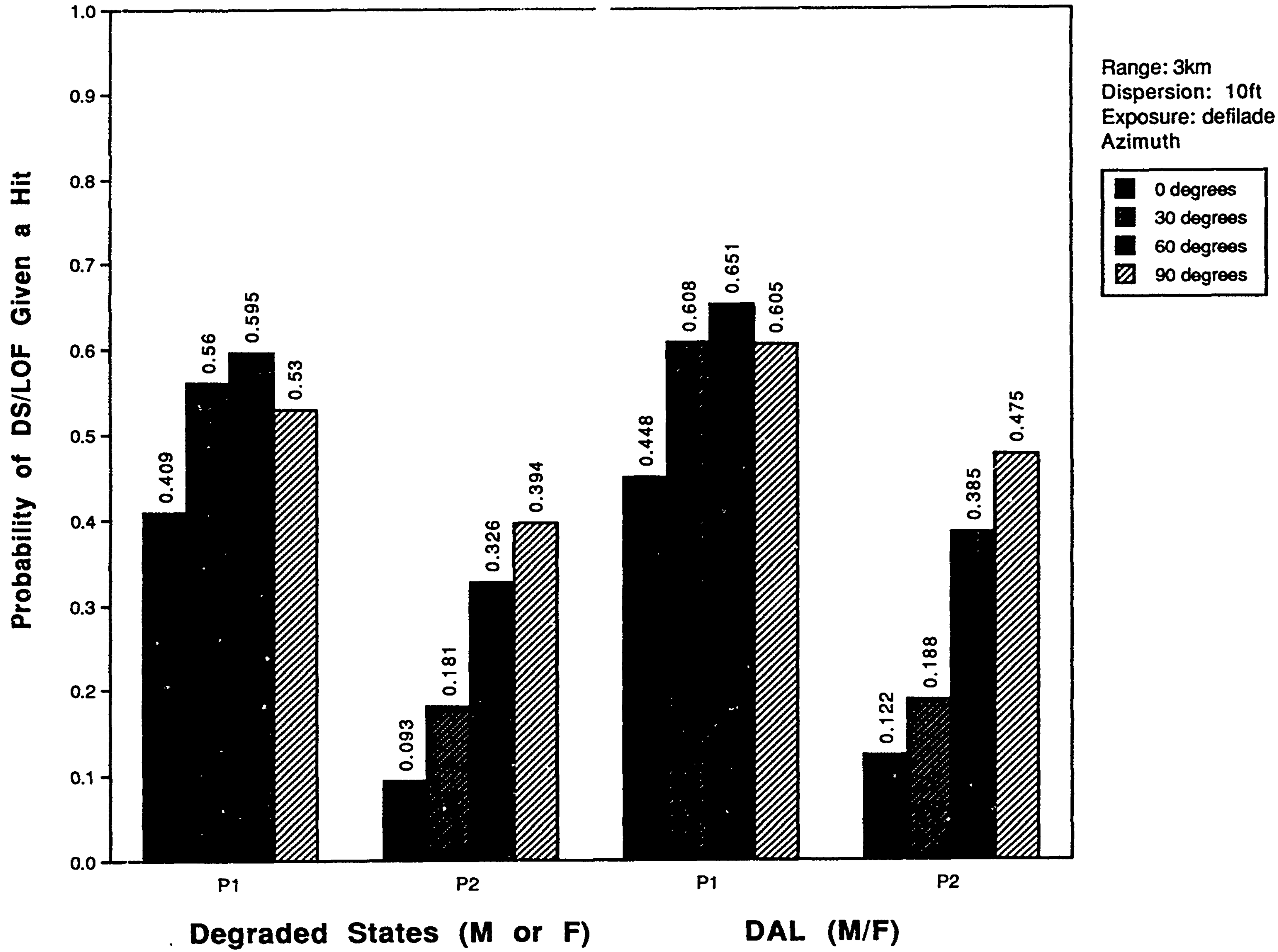


Figure C-28. Degraded States and DAL Azimuth Sensitivity

APPENDIX D

Degraded States vs. DAL Comparisons

INTENTIONALLY LEFT BLANK.

This appendix contains the numerical comparisons of the two methodologies' results. At the range of 1 kilometer and with a 2 foot dispersion value, the DS probabilities and DAL LOF values are compared for both threats and exposures. The DS values are probabilities given a hit extracted from the probability distribution output for each set of initial conditions. The DAL values are LOF given a hit from the basic and modified DALs.

INTENTIONALLY LEFT BLANK.

Threat: P1
Range: 1 km
Azimuth: 0 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.005		
	Reduced speed, significant	0.038		
	Total immobilization	0.615		
		0.658	0.725	0.645
FIREPOWER	Loss of main armament	0.487		
	Increased time to fire Reduced delivery accuracy	0.021		
	Unable to fire on the move Increased time to fire Reduced delivery accuracy	0.229		
	Loss of main armament Loss of secondary armament	0.090		
		0.827	0.810	0.783
ACQUISITION	Reduced acquisition capability	0.020		
	Reduced acquisition capability Unable to acquire while moving	0.773		
		0.793	?	
CREW	One crew casualty	0.387		
	Two crew casualties	0.133		
	Three crew casualties	0.052		
	Four crew casualties	0.090		
		0.662	?	
COMMO	No internal communications No external communications	0.479		
		0.479	?	
AMMUNITION	Bustle ammo lost	0.006		
		0.006	?	?
K-kill		0.090	0.090	0.090

Figure D-1. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 30 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.021		
	Reduced speed, significant	0.119		
	Total immobilization	0.587		
		0.727	0.768	0.679
FIREPOWER	Loss of main armament	0.512		
	Increased time to fire Reduced delivery accuracy	0.036		
	Unable to fire on the move Increased time to fire Reduced delivery accuracy	0.165		
	Loss of main armament Loss of secondary armament	0.093		
		0.806	0.779	0.756
ACQUISITION	Reduced acquisition capability	0.026		
	Reduced acquisition capability Unable to acquire while moving	0.770		
		0.796	?	
CREW	One crew casualty	0.254		
	Two crew casualties	0.122		
	Three crew casualties	0.038		
	Four crew casualties	0.091		
		0.505	?	
COMMO	No internal communications No external communications	0.561		
		0.561	?	
AMMUNITION	Bustle ammo lost	0.004		
	Hull ammo lost	0.004	?	?
		0.008		
K-kill		0.090	0.090	0.090

Figure D-2. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 60 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.063		
	Reduced speed, significant	0.268		
	Total immobilization	0.417		
		0.748	0.731	0.606
FIREPOWER	Loss of main armament	0.528		
	Increased time to fire Reduced delivery accuracy	0.045		
	Unable to fire on the move Increased time to fire Reduced delivery accuracy	0.198		
	Loss of main armament Loss of secondary armament	0.046		
		0.817	0.790	0.753
ACQUISITION	Reduced acquisition capability	0.026		
	Reduced acquisition capability Unable to acquire while moving	0.789		
		0.815	?	
CREW	One crew casualty	0.256		
	Two crew casualties	0.155		
	Three crew casualties	0.032		
	Four crew casualties	0.045		
		0.488	?	
COMMO	No internal communications No external communications	0.600		
		0.600	?	
AMMUNITION	Bustle ammo lost	0.005		
		0.005	?	?
K-kill		0.045	0.045	0.045

Figure D-3. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 90 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.035		
	Reduced speed, significant	0.307		
	Total immobilization	0.278		
		0.620	0.652	0.487
FIREPOWER	Loss of main armament	0.383		
	Increased time to fire			
	Reduced delivery accuracy	0.057		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.252		
	Loss of main armament			
	Loss of secondary armament	0.028		
		0.720	0.711	0.638
ACQUISITION	Reduced acquisition capability	0.036		
	Reduced acquisition capability			
	Unable to acquire while moving	0.713		
		0.749	?	
CREW	One crew casualty	0.194		
	Two crew casualties	0.140		
	Three crew casualties	0.116		
	Four crew casualties	0.028		
		0.478	?	
COMMO	No internal communications			
	No external communications	0.497		
		0.497	?	
AMMUNITION	Bustle ammo lost	0.001		
		0.001	?	?
K-kill		0.028	0.027	0.027

Figure D-4. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 0 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.022		
	Total immobilization	0.183		
		0.205	0.324	0.197
FIREPOWER	Loss of main armament	0.529		
	Increased time to fire			
	Reduced delivery accuracy	0.007		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.050		
	Loss of main armament			
	Loss of secondary armament	0.094		
		0.680	0.730	0.674
ACQUISITION	Reduced acquisition capability	0.066		
	Reduced acquisition capability			
	Unable to acquire while moving	0.498		
		0.564	?	
CREW	One crew casualty	0.212		
	Two crew casualties	0.129		
	Three crew casualties	0.027		
	Four crew casualties	0.094		
		0.462	?	
COMMO	No internal communications			
	No external communications	0.233		
		0.233	?	
AMMUNITION	Bustle ammo lost	0.009		
		0.009	?	?
K-kill		0.094	0.093	0.093

Figure D-5. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 30 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.088		
	Total immobilization	0.148		
		0.236	0.374	0.206
FIREPOWER	Loss of main armament	0.526		
	Increased time to fire			
	Reduced delivery accuracy	0.005		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.085		
	Loss of main armament			
	Loss of secondary armament	0.098		
		0.714	0.757	0.707
ACQUISITION	Reduced acquisition capability	0.122		
	Reduced acquisition capability			
	Unable to acquire while moving	0.535		
		0.657	?	
CREW	One crew casualty	0.271		
	Two crew casualties	0.120		
	Three crew casualties	0.023		
	Four crew casualties	0.098		
		0.512	?	
COMMO	No internal communications			
	No external communications	0.386		
		0.386	?	
AMMUNITION	Bustle ammo lost	0.008		
	Hull ammo lost	0.004	?	?
		0.012		
K-kill		0.098	0.097	0.097

Figure D-6. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 60 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.167		
	Total immobilization	0.099		
		0.266	0.437	0.208
FIREPOWER	Loss of main armament	0.490		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.159		
	Loss of main armament			
	Loss of secondary armament	0.056		
		0.705	0.784	0.697
ACQUISITION	Reduced acquisition capability	0.125		
	Reduced acquisition capability			
	Unable to acquire while moving	0.530		
		0.655	?	
CREW	One crew casualty	0.255		
	Two crew casualties	0.213		
	Three crew casualties	0.034		
	Four crew casualties	0.056		
		0.558	?	
COMMO	No internal communications			
	No external communications	0.467		
		0.467	?	
AMMUNITION	Bustle ammo lost	0.009		
		0.009	?	?
K-kill		0.056	0.056	0.056

Figure D-7. DAL vs. DS numerical comparison

Threat: P1
Range: 1 km
Azimuth: 90 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.287		
	Total immobilization	0.044		
		0.331	0.543	0.230
FIREPOWER	Loss of main armament	0.429		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.214		
	Loss of main armament			
	Loss of secondary armament	0.013		
		0.656	0.775	0.642
ACQUISITION	Reduced acquisition capability	0.105		
	Reduced acquisition capability			
	Unable to acquire while moving	0.576		
		0.681	?	
CREW	One crew casualty	0.141		
	Two crew casualties	0.298		
	Three crew casualties	0.174		
	Four crew casualties	0.013		
		0.626	?	
COMMO	No internal communications			
	No external communications	0.609		
		0.609	?	
AMMUNITION	Bustle ammo lost			
			?	?
K-kill		0.013	0.014	0.014

Figure D-8. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 0 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.004		
	Total immobilization	0.075		
		0.079	0.113	0.082
FIREPOWER	Loss of main armament	0.127		
	Increased time to fire			
	Reduced delivery accuracy	0.002		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.013		
	Loss of main armament			
	Loss of secondary armament	0.005		
		0.147	0.147	0.144
ACQUISITION	Reduced acquisition capability	0.018		
	Reduced acquisition capability			
	Unable to acquire while moving	0.114		
		0.132	?	
CREW	One crew casualty	0.031		
	Two crew casualties	0.023		
	Three crew casualties	0.027		
	Four crew casualties	0.005		
		0.086	?	
COMMO	No internal communications			
	No external communications	0.038		
		0.038	?	
AMMUNITION	Bustle ammo lost	0.003		
		0.003	?	?
K-kill		0.005	0.005	0.005

Figure D-9. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 30 degrees
Exposure: fully
Dispersion: 2 ft

	DEGRADED STATES		DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.066		
	Reduced speed, slight	0.057		
	Total immobilization	0.297		
		0.420	0.377	0.356
FIREPOWER	Loss of main armament	0.135		
	Increased time to fire Reduced delivery accuracy Unable to fire on the move	0.021		
	Increased time to fire Reduced delivery accuracy Loss of main armament	0.081		
	Loss of secondary armament	0.012		
		0.249	0.225	0.218
ACQUISITION	Reduced acquisition capability	0.012		
	Reduced acquisition capability Unable to acquire while moving	0.236	?	
		0.248		
CREW	One crew casualty	0.052		
	Two crew casualties	0.016		
	Three crew casualties	0.006		
	Four crew casualties	0.012	?	
		0.086		
COMMO	No internal communications No external communications	0.101	?	
		0.101		
AMMUNITION	Bustle ammo lost	0.001	?	?
		0.001		
K-kill		0.012	0.011	0.011

Figure D-10. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 60 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.075		
	Reduced speed, significant	0.258		
	Total immobilization	0.348		
		0.681	0.646	0.533
FIREPOWER	Loss of main armament	0.447		
	Increased time to fire Reduced delivery accuracy	0.044		
	Unable to fire on the move Increased time to fire Reduced delivery accuracy	0.194		
	Loss of main armament Loss of secondary armament	0.011		
		0.696	0.676	0.632
ACQUISITION	Reduced acquisition capability	0.021		
	Reduced acquisition capability Unable to acquire while moving	0.689		
		0.710	?	
CREW	One crew casualty	0.211		
	Two crew casualties	0.121		
	Three crew casualties	0.032		
	Four crew casualties	0.011		
		0.375	?	
COMMO	No internal communications No external communications	0.487		
		0.487	?	
AMMUNITION	Bustle ammo lost	0.002		
	Hull ammo lost	0.001	?	?
		0.003		
K-kill		0.011	0.010	0.010

Figure D-11. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 90 degrees
Exposure: fully
Dispersion: 2 ft

DEGRADED STATES			DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, slight	0.036		
	Reduced speed, significant	0.284		
	Total immobilization	0.250		
		0.570	0.605	0.447
FIREPOWER	Loss of main armament	0.341		
	Increased time to fire Reduced delivery accuracy	0.058		
	Unable to fire on the move Increased time to fire Reduced delivery accuracy Loss of main armament	0.255		
	Loss of secondary armament	0.025		
		0.679	0.667	0.594
ACQUISITION	Reduced acquisition capability	0.036		
	Reduced acquisition capability Unable to acquire while moving	0.676		
		0.712	?	
CREW	One crew casualty	0.173		
	Two crew casualties	0.128		
	Three crew casualties	0.104		
	Four crew casualties	0.025		
		0.430	?	
COMMO	No internal communications No external communications	0.454		
		0.454	?	
AMMUNITION	Bustle ammo lost	0.002		
		0.002	?	?
K-kill		0.025	0.024	0.024

Figure D-12. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 0 degrees
Exposure: defilade
Dispersion: 2 ft

	DEGRADED STATES		DAL Basic	DAL No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.002		
	Total immobilization	0.021		
		0.023	0.054	0.022
FIREPOWER	Loss of main armament	0.130		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.024		
	Loss of main armament			
	Loss of secondary armament	0.020		
		0.174	0.197	0.179
ACQUISITION	Reduced acquisition capability	0.026		
	Reduced acquisition capability			
	Unable to acquire while moving	0.073		
		0.099	?	
CREW	One crew casualty	0.039		
	Two crew casualties	0.019		
	Three crew casualties	0.012		
	Four crew casualties	0.020		
		0.090	?	
COMMO	No internal communications			
	No external communications	0.025		
		0.025	?	
AMMUNITION	Bustle ammo lost	0.007		
		0.007	?	?
K-kill		0.020	0.020	0.020

Figure D-13. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 30 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.020		
	Total immobilization	0.005		
		0.025	0.036	0.017
FIREPOWER	Loss of main armament	0.116		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.048		
	Loss of main armament			
	Loss of secondary armament	0.005		
		0.169	0.187	0.168
ACQUISITION	Reduced acquisition capability	0.042		
	Reduced acquisition capability			
	Unable to acquire while moving	0.078		
		0.120	?	
CREW	One crew casualty	0.045		
	Two crew casualties	0.011		
	Three crew casualties	0.002		
	Four crew casualties	0.005		
		0.063	?	
COMMO	No internal communications			
	No external communications	0.020		
		0.020	?	
AMMUNITION	Bustle ammo lost	0.001		
		0.001	?	?
K-kill		0.005	0.005	0.005

Figure D 14. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 60 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.111		
	Total immobilization	0.019		
		0.130	0.241	0.093
FIREPOWER	Loss of main armament	0.168		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.115		
	Loss of main armament			
	Loss of secondary armament	0.007		
		0.290	0.361	0.285
ACQUISITION	Reduced acquisition capability	0.058		
	Reduced acquisition capability			
	Unable to acquire while moving	0.247		
		0.305	?	
CREW	One crew casualty	0.113		
	Two crew casualties	0.127		
	Three crew casualties	0.293		
	Four crew casualties	0.007		
		0.046	?	
COMMO	No internal communications			
	No external communications	0.278		
		0.278	?	
AMMUNITION	Bustle ammo lost	0.004		
		0.004	?	?
K-kill		0.007	0.007	0.007

Figure D-15. DAL vs. DS numerical comparison

Threat: P2
Range: 1 km
Azimuth: 90 degrees
Exposure: defilade
Dispersion: 2 ft

DEGRADED STATES			DAL	
			Basic	No crew or commo or acquisition
MOBILITY	Reduced speed, significant	0.247		
	Total immobilization	0.018		
		0.265	0.466	0.178
FIREPOWER	Loss of main armament	0.286		
	Unable to fire on the move			
	Increased time to fire			
	Reduced delivery accuracy	0.176		
	Loss of main armament			
	Loss of secondary armament	0.012		
		0.474	0.594	0.464
ACQUISITION	Reduced acquisition capability	0.088		
	Reduced acquisition capability			
	Unable to acquire while moving	0.462		
		0.550	?	
CREW	One crew casualty	0.084		
	Two crew casualties	0.272		
	Three crew casualties	0.168		
	Four crew casualties	0.011		
		0.535	?	
COMMO	No internal communications			
	No external communications	0.541		
		0.541	?	
AMMUNITION				
K-kill		0.011	0.012	0.012

Figure D-16. DAL vs. DS numerical comparison

APPENDIX E

Aggregated Degraded States vs. DAL Comparisons

INTENTIONALLY LEFT BLANK.

This appendix contains line graphs which illustrate the numerical comparisons of the aggregated DS probabilities and the basic DAL LOF values. The values being compared are described as follows: DS "hardware only" probabilities give the probability of some damage to a particular kill category; DS aggregated probabilities give the probability of some damage to any of several kill categories; and, DAL LOF values are from the basic DAL.

INTENTIONALLY LEFT BLANK.

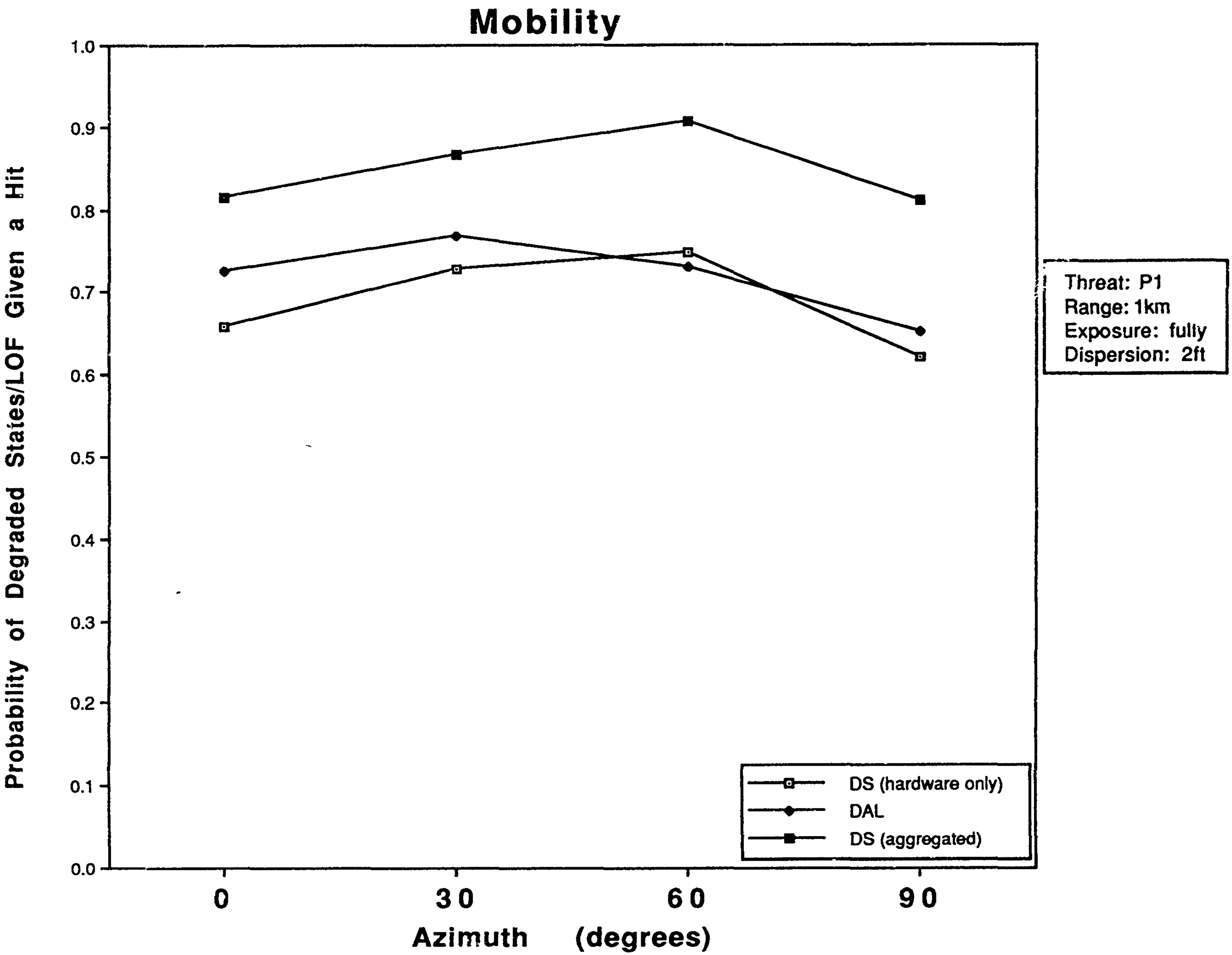


Figure E-1. Aggregated DS vs. DAL Comparison

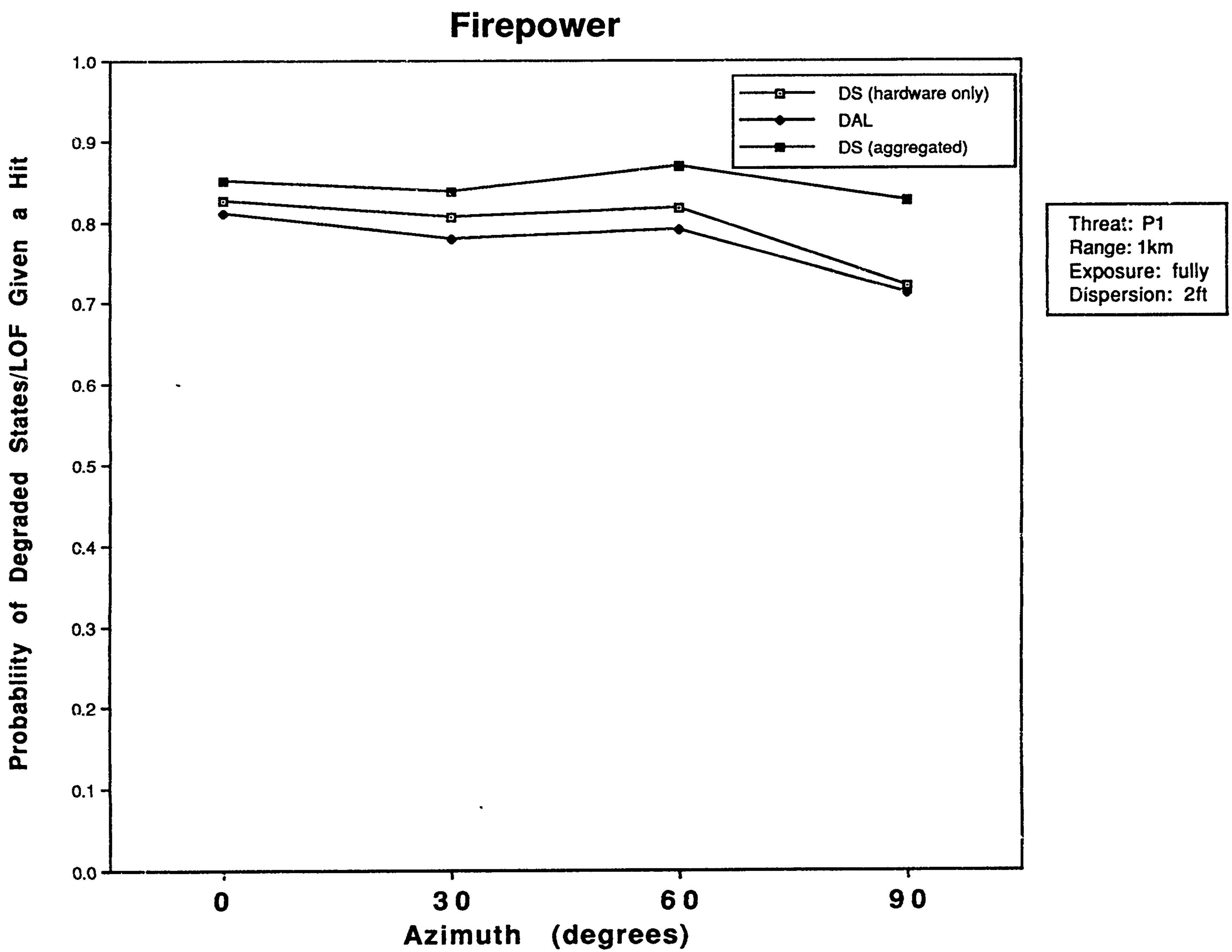


Figure E-2. Aggregated DS vs. DAL Comparison

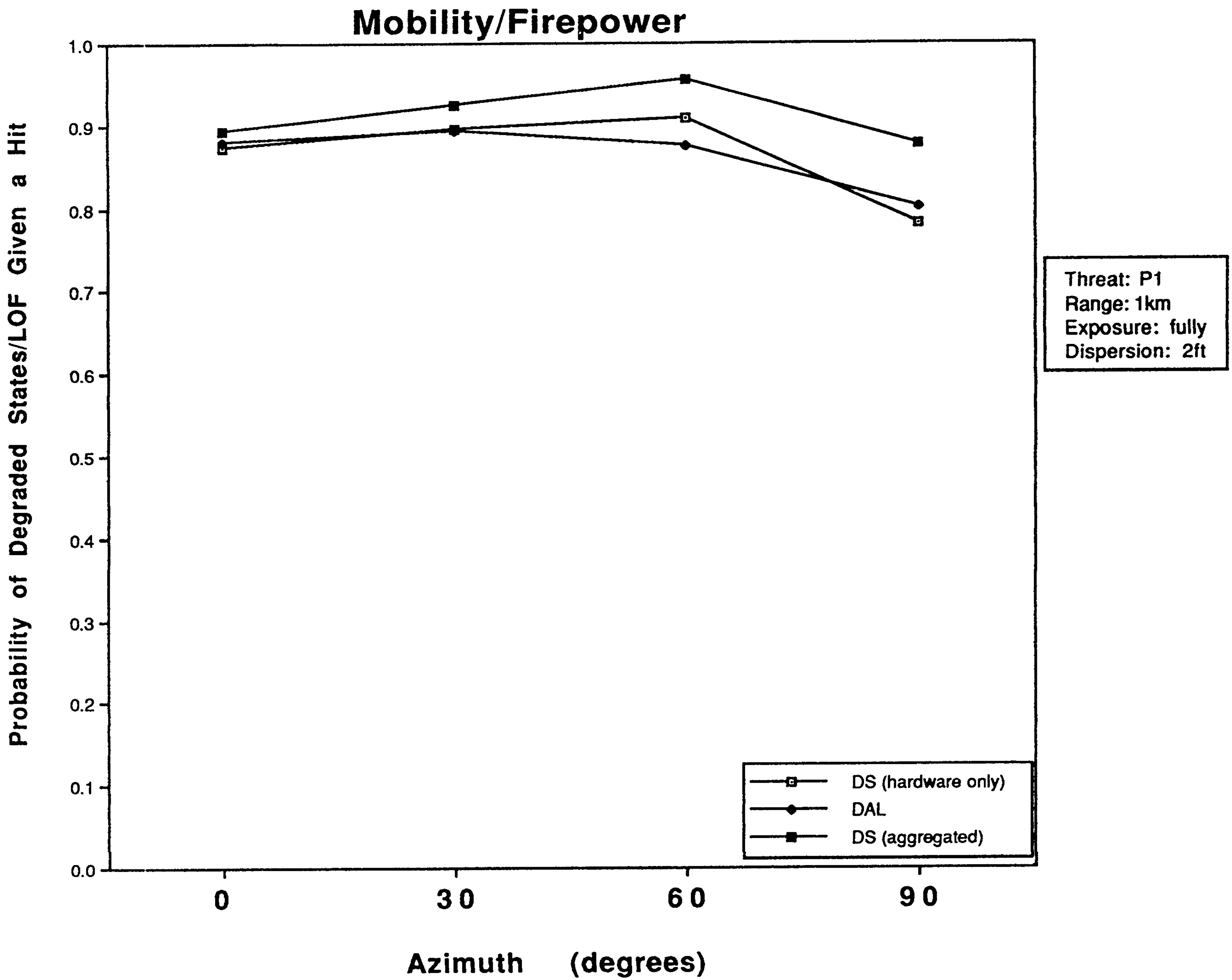


Figure E-3. Aggregated DS vs. DAL Comparison

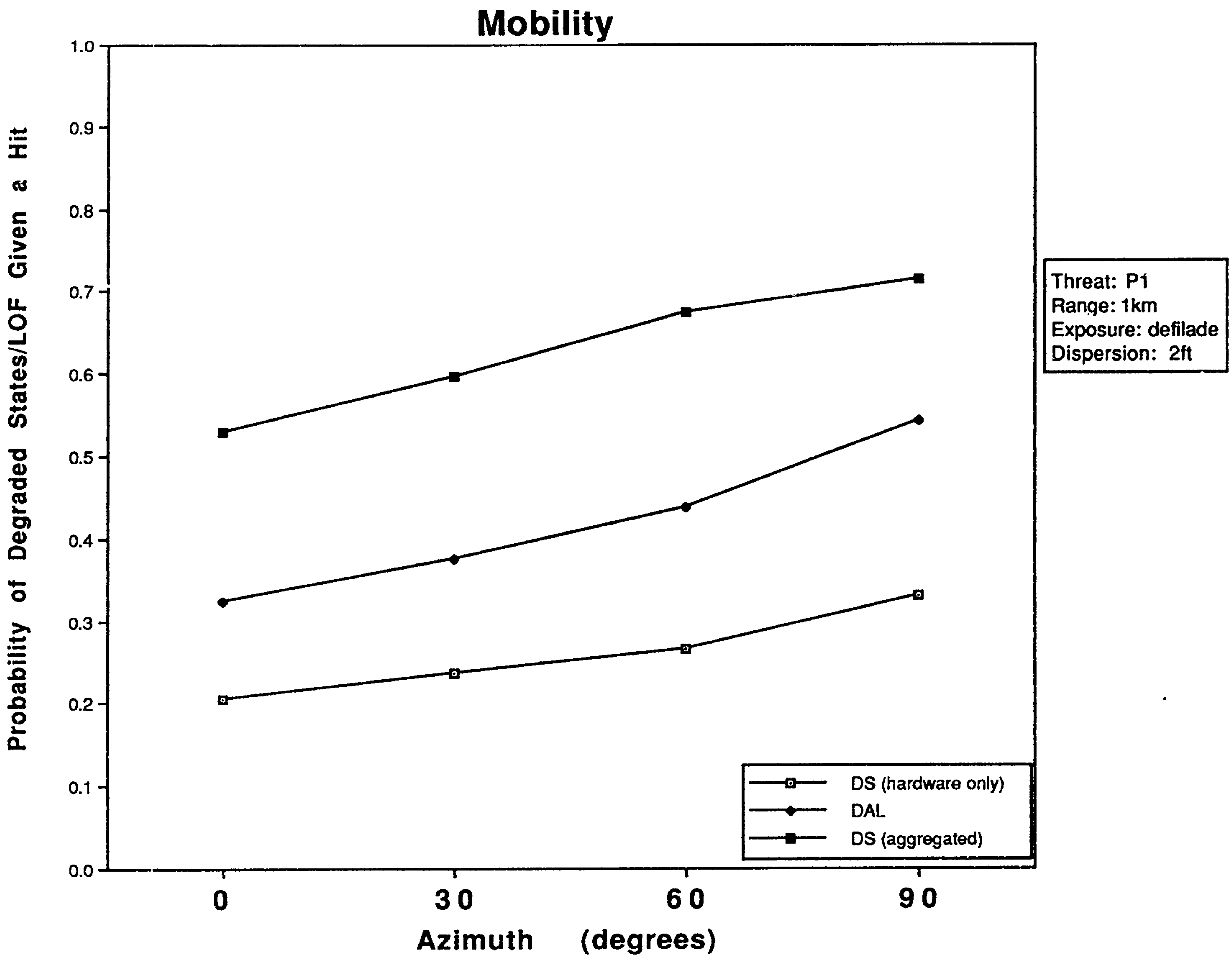


Figure E-4. Aggregated DS vs. DAL Comparison

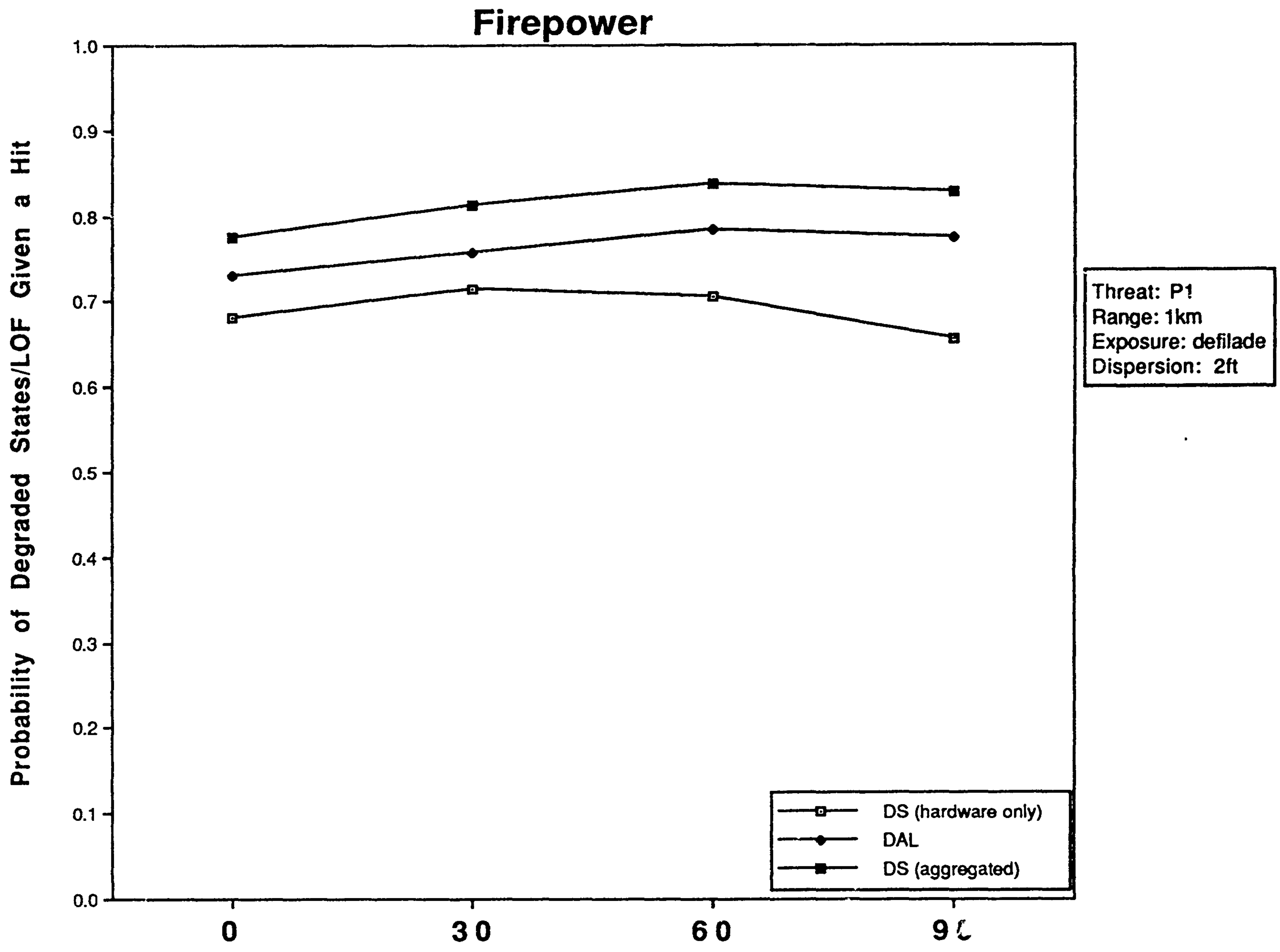


Figure E-5. Aggregated DS vs. DAL Comparison

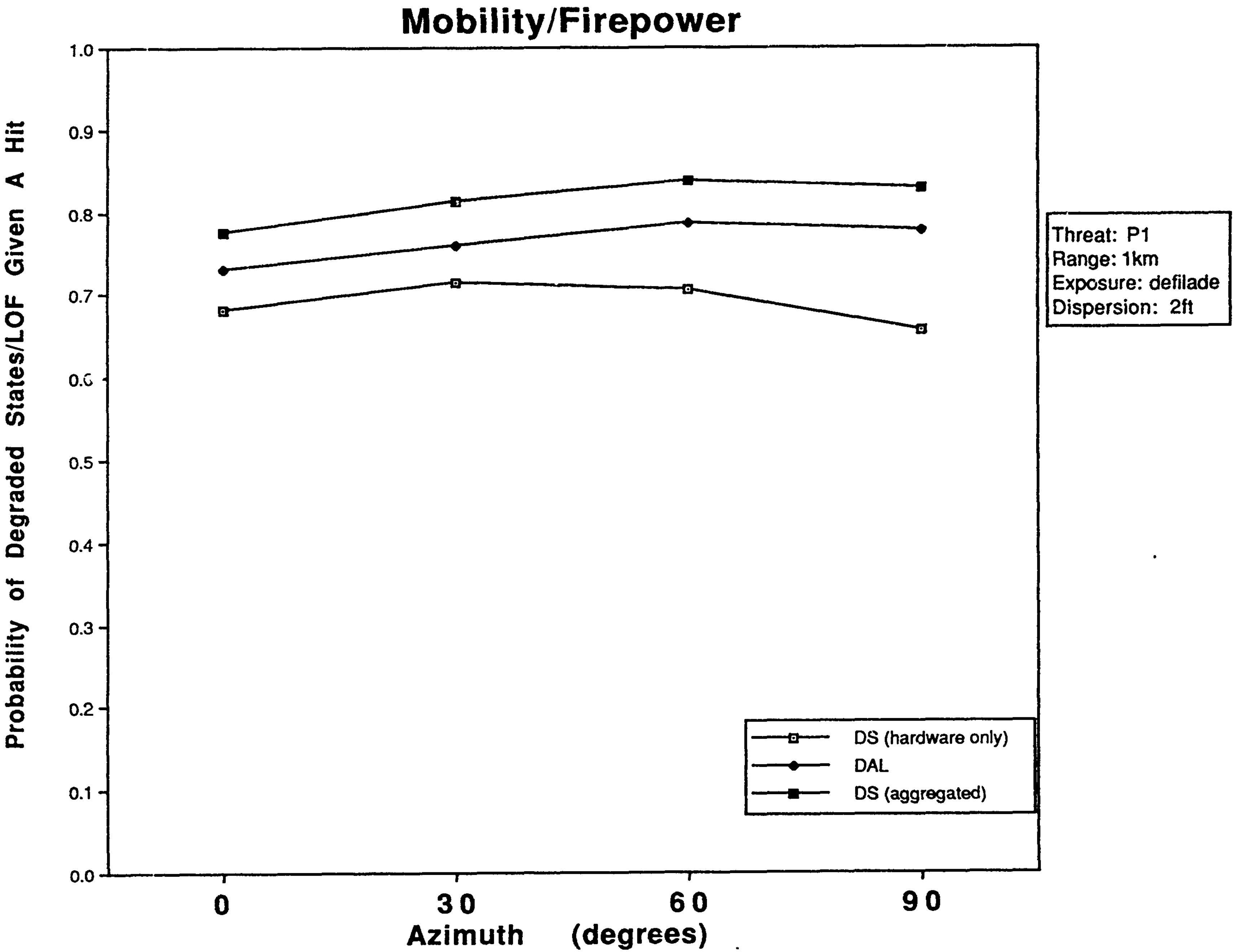


Figure E-6. Aggregated DS vs. DAL Comparison

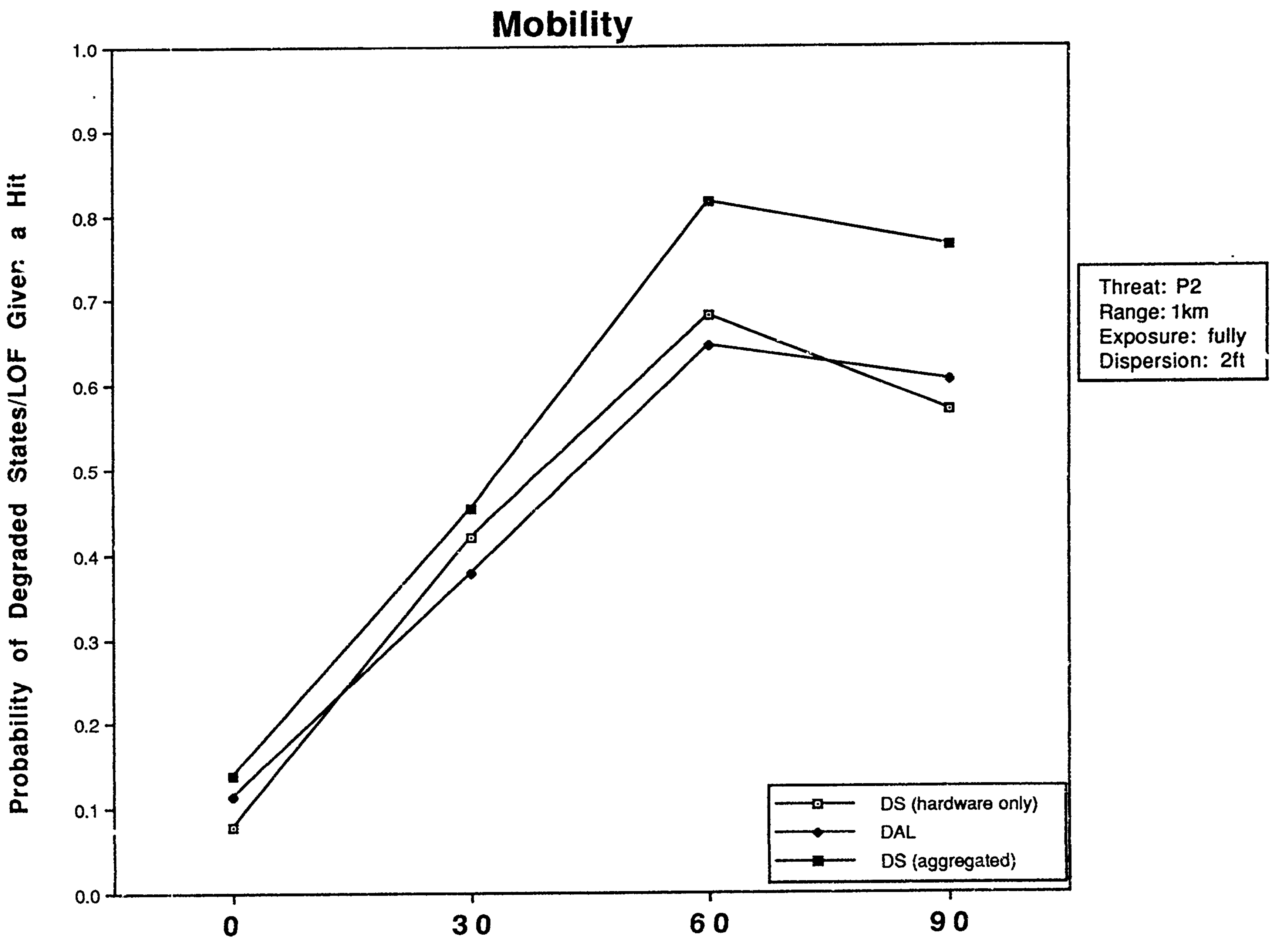


Figure E-7. Aggregated DS vs. DAL Comparison

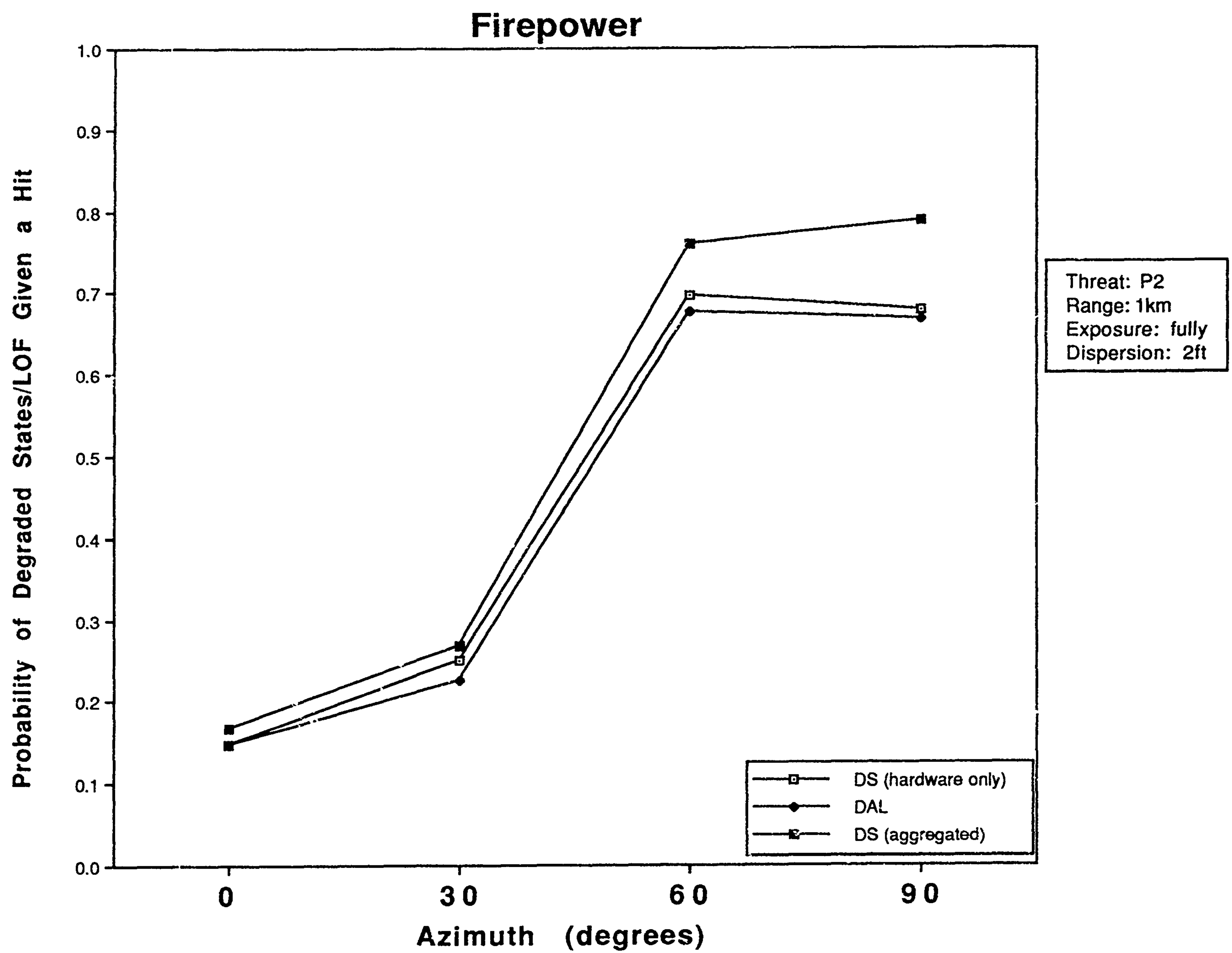


Figure E-8. Aggregated DS vs. DAL Comparison

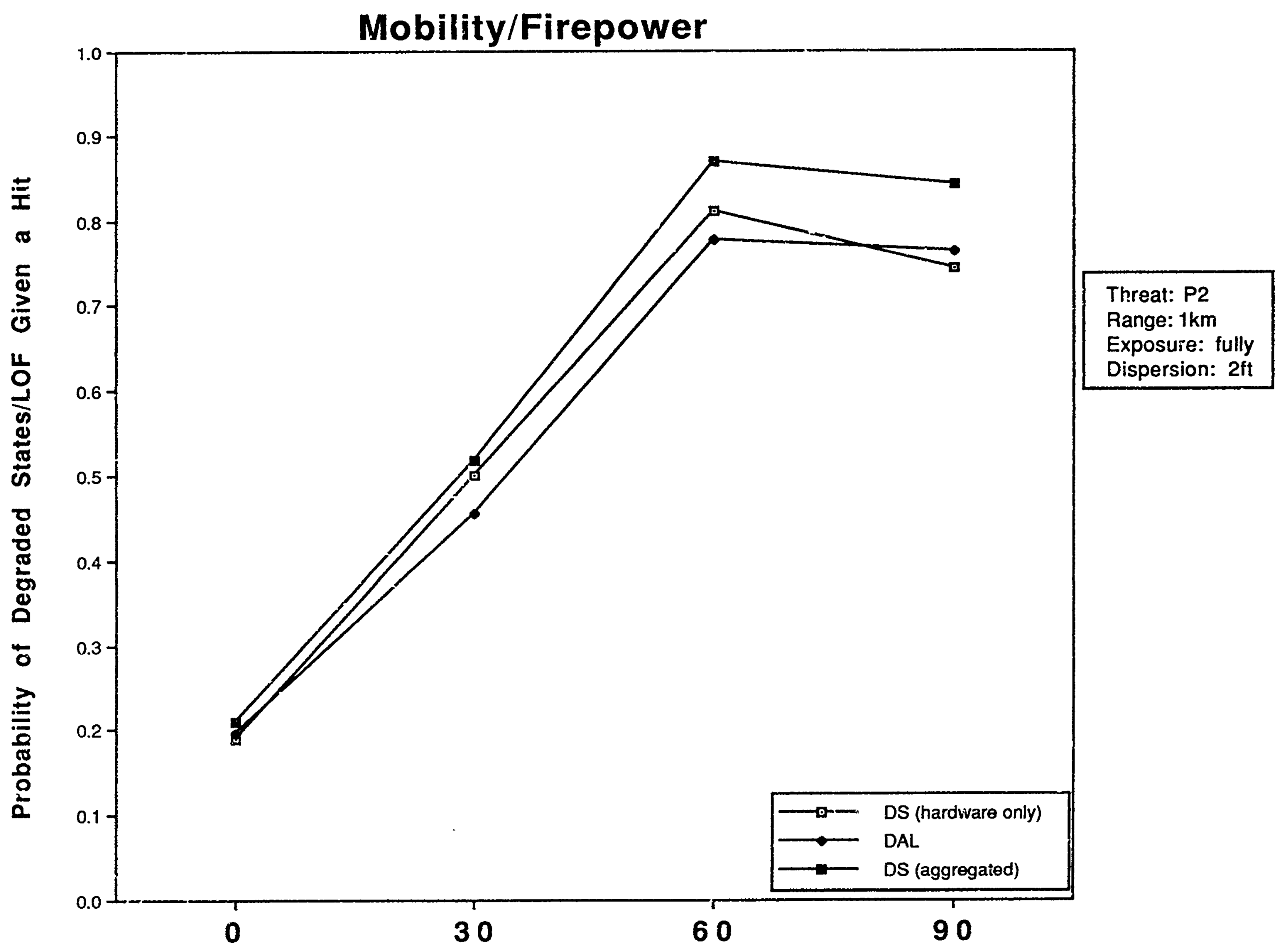


Figure E-9. Aggregated DS vs. DAL Comparison

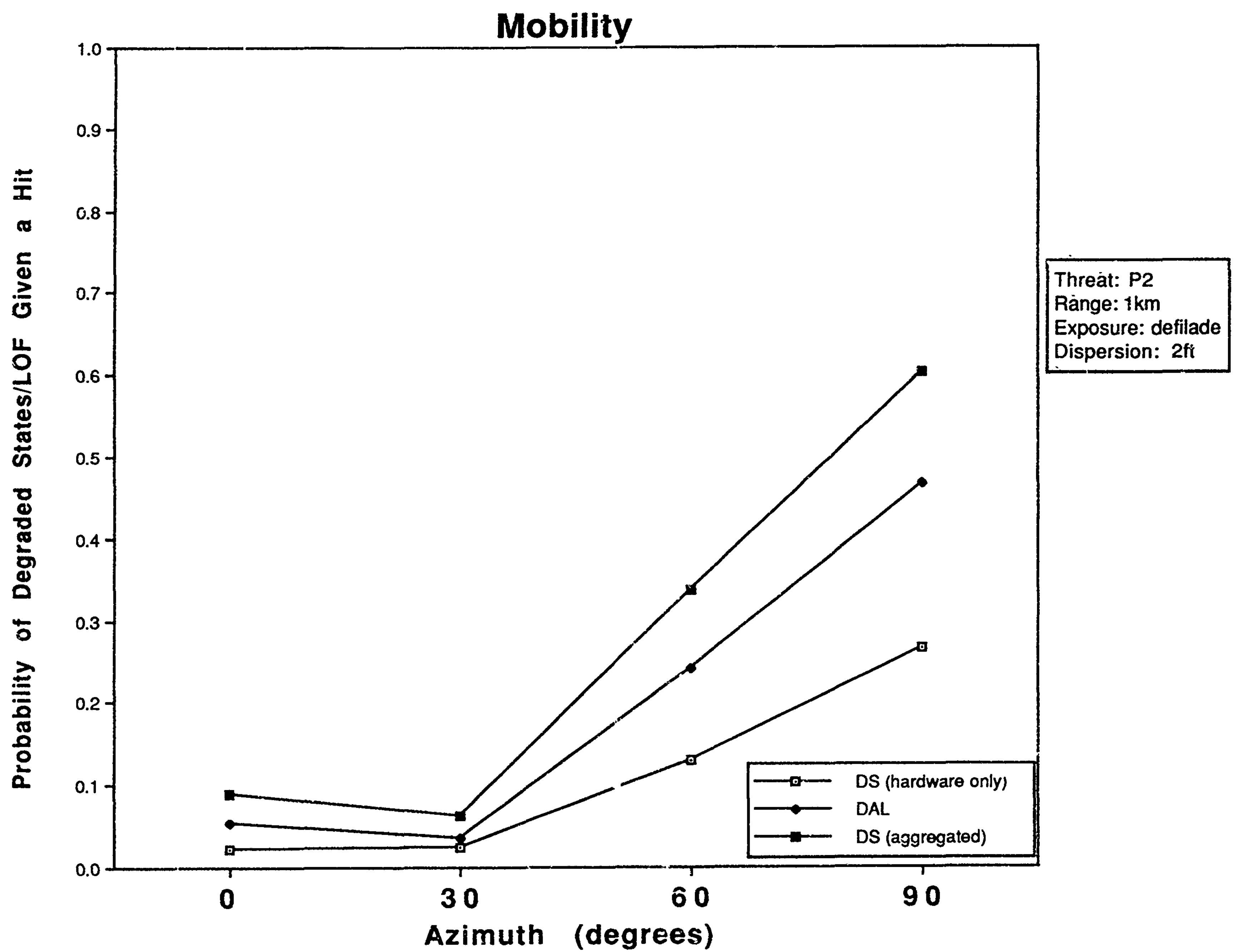


Figure E-10. Aggregated DS vs. DAL Comparison

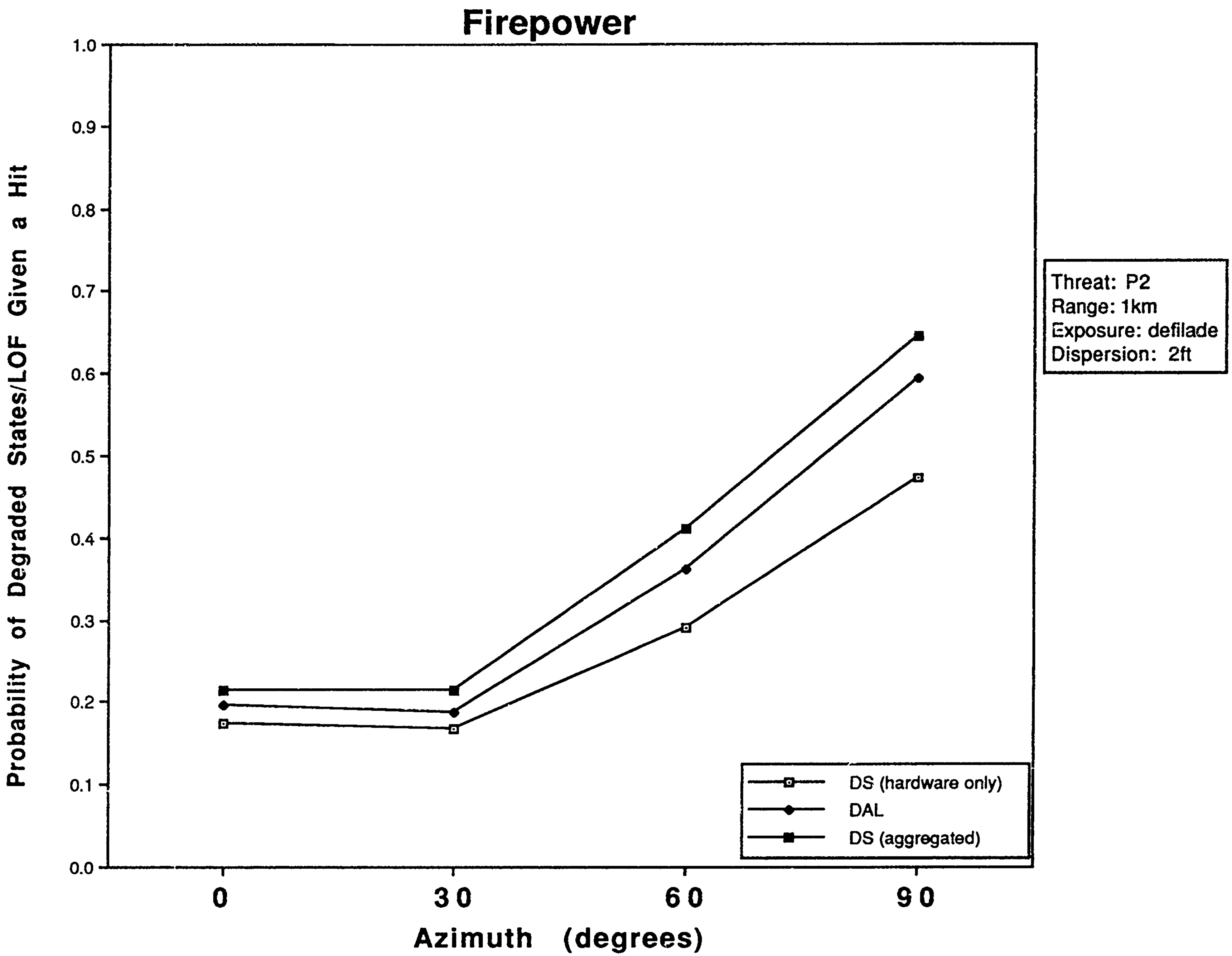


Figure E-11. Aggregated DS vs. DAL Comparison

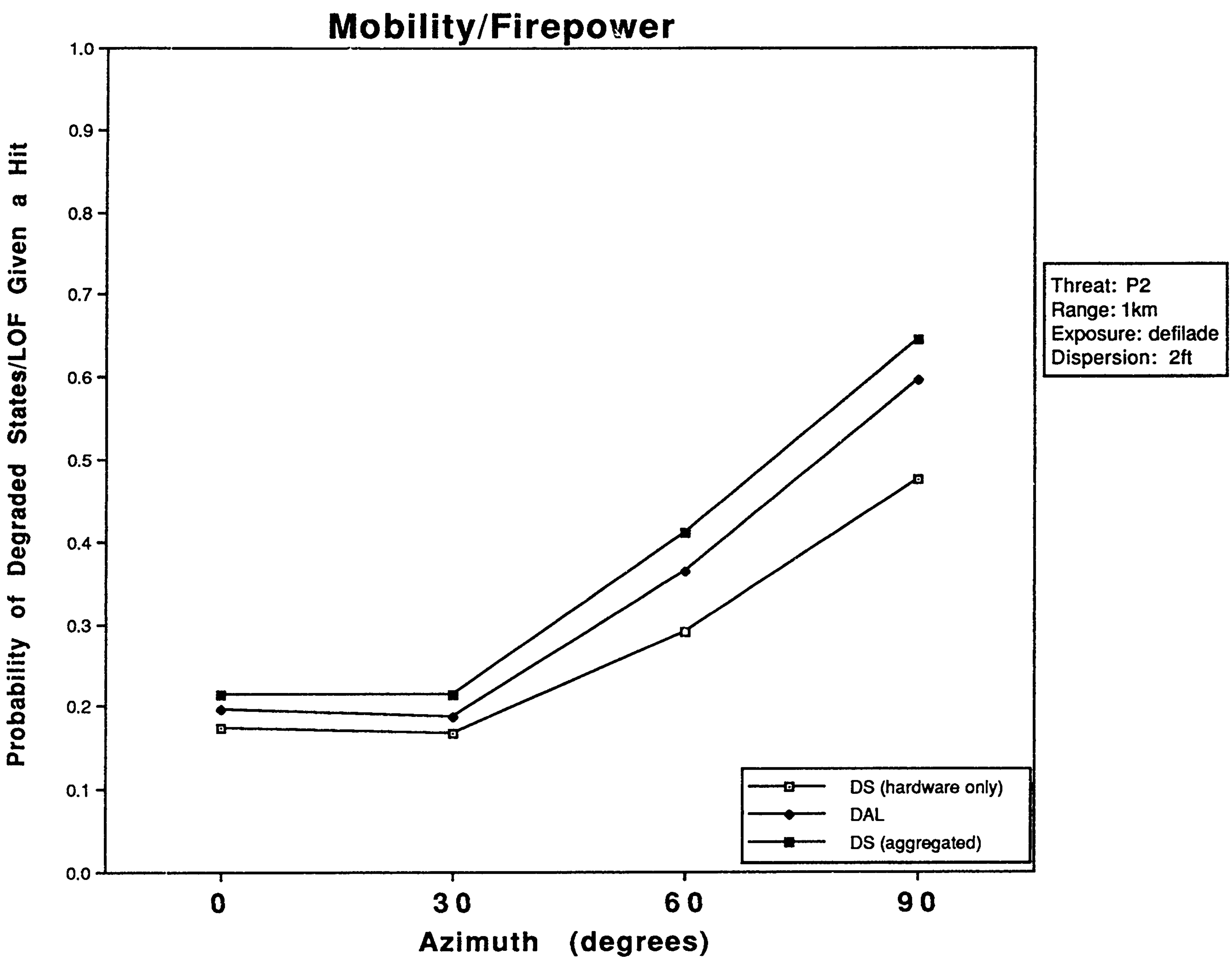


Figure E-12. Aggregated DS vs. DAL Comparison

No of Copies	Organization
1	Office of the Secretary of Defense OUSD(A) Director, Live Fire Testing ATTN: James F. O'Bryon Washington, DC 20301-3110
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQDA (SARD-TR) WASH DC 20310-0001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
2	Commander US Army, ARDEC ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory US Army, ARDEC ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000
1	Commander US Army Aviation Systems Command ATTN: AMSAV-DACL 4300 Goodfellow Blvd. St. Louis, MO 63120-1798

No of Copies	Organization
1	Director US Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000
1	Commander US Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-TSL (Technical Library) Warren, MI 48397-5000
1	Director US Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TD
3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
1	Dir, VLAMO ATTN: AMSLC-VL-D

No. of Copies	Organization
10	C.I.A. OIR/DB/Standard GE47 HQ Washington, DC 20505
1	HQDA (DAMI-FIT, COL O'Connor) WASH DC 20310-1001
1	HQDA (DAMO-ZD, Mr. Riente) The Pentagon, Rm 3A538 WASH DC 20310-0410
1	HQDA (SARD-TN, LTC Fejfar) The Pentagon, Rm 3E360 WASH DC 20310
1	HQDA (Asst Chief of Staff for Intelligence, Joseph Varandore) WASH DC 20310-1067
1	HQDA (Limres Study Group, Shirley D. Ford) The Pentagon, Room 1B929 WASH DC 20310
1	Office of the Assistant Secretary of the Army (Research, Development, and Acquisition) ATTN: LTG Donald S. Pihl, Military Deputy Washington, DC 20310-0100
1	Office of the Secretary of the Army (Research, Development, and Acquisition) ATTN: MG Cercy Deputy for Systems Management Washington, DC 20310-0103
1	Deputy Under Secretary of the Army for Operations Research ATTN: OUSA (Hon Walt Hollis) The Pentagon, Room 2E660 Washington, DC 20310-0102

No. of Copies	Organization
1	Office of the Under Secretary of Defense, R&E ATTN: Dr. William Snowden The Pentagon, Room 3D359 Washington, DC 20301
1	Office of the Asst Dep Dir of Defense Live Fire Testing ATTN: COL L. Stanford The Pentagon, Room 3E1060 Washington, DC 20301
1	OSD OUSD (A) ODDDRE (T&E/LFT) ATTN: Albert E. Rainis The Pentagon, Rm 3E1060 Washington, DC 20301-3110
1	American Defense Preparedness Association (ADPA) ATTN: Bill King 1700 N. Moore Street, #900 Arlington, VA 22209-1942
9	Defense Advanced Research Projects Agency ATTN: Mr. B. Bandy Dr. R. Kahn Dr. C. Kelly Mr. P. Losleben Dr. J. Lupo Mr. F. Patten Dr. Reynolds Mr. S. Squires COL J. Thorpe 1400 Wilson Boulevard Arlington, VA 22209
2	Central Intelligence Agency ATTN: ORD/PERD (Ray Cwiklinski) (Tom Kennedy) Washington, DC 20505
1	Central Intelligence Agency ATTN: ORD (Jim Fahnestock) Washington, DC 20505

No. of Copies	Organization
1	Central Intelligence Agency ATTN: ORD/IERD (J. Fleisher) Washington, DC 20505
1	Central Intelligence Agency ATTN: ORD (Marvin P. Hartzler) Washington, DC 20505
2	Central Intelligence Agency ATTN: OIA (Barbara A. Kroggel) (Monica McGuinn) Washington, DC 20505
1	Central Intelligence Agency ATTN: ORD (Peter Lew) 1820 N. Fort Meyer Drive Arlington, VA 22209
1	Central Intelligence Agency ATTN: ORD (Donald Gorson) 1820 N. Fort Meyer Drive Arlington, VA 22209
1	Chief of Naval Operations OP-03-C2 ATTN: CPT Robert K. Barr Rm 4D537, The Pentagon Washington, DC 20350-2000
1	Mr. Robert Gomez/OSWR PO Box 1925 Washington, DC 20013
1	Commander US Army Materiel Command ATTN: AMCDE-PI (Dan Marks) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Headquarters US Army Materiel Command ATTN: AMCDRA (R. Black) 5001 Eisenhower Avenue Alexandria, VA 22333-0001

No. of Copies	Organization
1	Commander US Army Materiel Command ATTN: AMCMT (John Kicak) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Materiel Command ATTN: AMCPD (Darold Griffin) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Materiel Command ATTN: AMCPD-PM (Jim Sullivan) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
2	Commander US Army Materiel Command ATTN: AMCPM-LOTA (Robert Hall) (MAJ Purdin) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Materiel Command ATTN: AMCSP 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Materiel Command ATTN: AMCTD-PT (Alan Elkins) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-CT (K. Zastrow) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander US Army Laboratory Command ATTN: AMSLC-CG 2800 Powder Mill Road Adelphi, MD 20783-1145

No. of Copies	Organization
1	Commander US Army Laboratory Command ATTN: AMSLC-LO (LTC P. Fardink) 2800 Powder Mill Road Adelphi, MD 20783-1145
2	Commander US Army Laboratory Command ATTN: AMSLC-TP (J. Predham) (D. Smith) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander US Army Laboratory Command ATTN: SLCTO (Marcos Sola) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commandant US Army Logistics Management College ATTN: AMXMC-LS-S (CPT(P) Stephen Parker) Ft. Lee, VA 23801
1	Commander US Army Materials Technology Laboratory ATTN: SLCMT-ATL Watertown, MA 02172-0001
3	Director US Army Research Office ATTN: SLCRO-MA (Dr. J. Chandra) (Dr. K. Clark) (Dr. Wu) P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Director US Army Survivability Management Office ATTN: SLCSM-C31 (H. J. Davis) 2800 Powder Mill Road Adelphi, MD 20783

No. of Copies	Organization
1	Director US Army Survivability Management Office ATTN: SLCSM-D (COL H. Head) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander US Army, ARDEC ATTN: SMCAR-CCH-V (Paul H. Gemmill) Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-FSS-E (Jack Brooks) Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-TD (Jim Killen) Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-TDS (Vic Lindner) Picatinny Arsenal, NJ 07806-5000
1	Commander US Army Aviation Systems Command ATTN: AMSAV-ES 4300 Goodfellow Blvd St Louis, MO 63120-1798
1	Commander US Army Aviation Systems Command ATTN: AMSAV-GT (R. Lewis) 4300 Goodfellow Blvd St. Louis, MO 63120-1798
2	Commander US Army Aviation Systems Command ATTN: AMSAV-NC (H. Law) (S. Meyer) 4300 Goodfellow Blvd St. Louis, MO 63120-1798

No. of Copies	Organization
1	Commander Belvoir Research, Development and Engineering Center ATTN: STRBE-FC (Ash Patil) Fort Belvo.r, VA 22060-5606
1	Commander Belvoir Research, Development and Engineering Center ATTN: STRBE-JDA (Melvin Goss) Fort Belvoir, VA 22060-5606
1	Commander, USACECOM R&D Technical Library ATTN: ASQNC-ELC-I-T, Myer Center Fort Monmouth, NJ 07703-5000
1	Director Center for Night Vision and Electro-Optics ATTN: AMSEL-NV-V (John Palmer) Fort Belvoir, VA 22060-5677
1	Director Center for Night Vision and Electro-Optics ATTN: AMSEL-RD-NV-V (John Ho) Fort Belvoir, VA 22060-5677
1	Director Center for Night Vision and Electro-Optics ATTN: DELMV-L (Dr. R. Buser) Fort Belvoir, VA 22060-5677
1	Commander US Army Foreign Science and Technology Center ATTN: AIF (Bill Rich) 220 Seventh Street, NE Charlottesville, VA 22901-5396
3	Commander US Army Foreign Science and Technology Center ATTN: AIFRC (T. Walker) (S. Eitleman) (R. Witnebal) 220 Seventh Street. NE Charlottesville, VA 22901-5396

No. of Copies	Organization
1	Commander US Army Foreign Science and Technology Center ATTN: AIFRS (Gordon Spencer) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander US Army Foreign Science and Technology Center ATTN: AIFRT (John Kosiewicz) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander US Army Foreign Science and Technology Center ATTN: AIFRC (Dave Hardin) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander US Army Foreign Science and Technology Center ATTN: AMXST-WSI (John R. Aker) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander US Army Harry Diamond Laboratories ATTN: SLCHD-RT (Peter Johnson) 2800 Powder Mill Road Adelphi, MD 20783-1197
1	Commander US Army INSCOM ATTN: IAOPS-SE-M (George Maxfield) Arlington Hall Station Arlington, VA 22212-5000
2	Commander US Army Missile Command ATTN: AMSMI-RD-GC-T (R. Alongi) Redstone Arsenal, AL 35898-5000
1	Commander US Army Missile Command ATTN: AMSMI-RD-SS-AT (Ed Vaughn) Redstone Arsenal, AL 35898-5000

No. of Copies	Organization
1	Commander US Army Missile Command ATTN: AMSMI-RGT (J. Bradas) Redstone Arsenal, AL 35898-5000
1	Commander US Army Missile Command ATTN: AMSMI-YTSD (Glenn Allison) Redstone Arsenal, AL 35898-5070
1	Commander US Army Missile Command ATTN: AMSMI-REX (W. Pittman) Redstone Arsenal, AL 35898-5500
1	Director US Army Missile and Space Intelligence Center ATTN: AIAMS-RT (Pat Jordan) Redstone Arsenal, AL 35898-5500
1	Director US Army Missile and Space Intelligence Center ATTN: AIAMS-YLD (Vernon L. Stallcup) Redstone Arsenal, AL 35898-5500
2	Director US Army Missile and Space Intelligence Center ATTN: AIAMS-YRS, Thomas Blalock Pete Kirkland Redstone Arsenal, AL 35898-5500
2	Director US Army Missile and Space Intelligence Center ATTN: AIAMS-YRT, Francis G. Cline Don A. Slaymaker Redstone Arsenal, AL 35898-5500
1	Director US Army Missile and Space Intelligence Center ATTN: Randy L. Smith Redstone Arsenal, AL 35898-5500

No. of Copies	Organization
1	Commander US Army Natick R&D Center ATTN: STRNC-OI (Stephen A. Freitas) Natick, MA 01760
1	Commander US Army Tank-Automotive Command ATTN: SPAE-ASM-PEO/COL Don Derrah Warren, MI 48397-5000
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-CF (Dr. Oscar) Warren, MI 48090
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-CK (G. Orlicki) Warren, MI 48090
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-CR (Mr. Wheelock) Warren, MI 48397-5000
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-CV (COL Kearney) Warren, MI 48397-5000
2	Commander US Army Tank-Automotive Command ATTN: AMSTA-NKS (D. Cyaye) (J. Rowe) Warren, MI 48397-5000
2	Commander US Army Tank-Automotive Command ATTN: AMSTA-RGE (R. Munt) (R. McClelland) Warren, MI 48397-5000
3	Commander US Army Tank-Automotive Command ATTN: AMSTA-RSC (John Bennett) (Wally Mick) Warren, MI 48397-5000

No. of Copies	Organization
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-RSK (Sam Goodman) Warren, MI 48090-5000
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-VS (Brian Bonkosky) Warren, MI 48090-5000
6	Commander US Army Tank-Automotive Command ATTN: AMSTA-ZE (R. Asoklis) AMSTA-ZEA (C. Robinson) (R. Gonzalez) AMSTA-ZS (D. Rees) AMSTA-ZSS (J. Thompson) (J. Soltez) Warren, MI 48397-5000
1	Director HQ, TRAC RPD ATTN: Asst Dep Chief of Staff for Combat Operations Fort Monroe, VA 23651-5000
2	Director HQ, TRAC RPD ATTN: ATRC-RP (COL Brinkley) ATRC-RPR (Mark W. Murray) Ft. Monroe, VA 23651-5143
1	Director US Army Cold Regions Research and Development Laboratory ATTN: Technical Director (Lewis Link) 72 Lyme Road Hanover, NH 03755
1	US Army Corps of Engineers Assistant Director Research and Development Directorate ATTN: Mr. B. Benn 20 Massachusetts Avenue, NW Washington, DC 20314-1000

No. of Copies	Organization
1	Commander US Army Vulnerability Assessment Laboratory ATTN: SLCVA-CF (Gil Apodaca) White Sands Missile Range, NM 88002-5513
1	Director TRAC-WSMR ATTN: ATRC-RD (McCoy) WSMR, NM 88002-5502
2	US General Accounting Office Program Evaluation and Methodology Division ATTN: Robert G. Orwin Joseph Sonnefeld Room 5844 441 G Street, NW Washington, DC 20548
1	Director Office of the Deputy Under Secretary of the Army, Operations Research Study Program Management Agency ATTN: SFUS-SPM/E. Visco Washington, DC 20310-0102
1	Director US Army Industrial Base Engineering Activity ATTN: AMXIB-MT Rock Island, IL 61299-7260
1	Director US Army Industrial Base Engineering Activity ATTN: AMXIB-PS (Steve McGlone) Rock Island, IL 61299-7260
3	Director US Army Engineer Waterways Experiment Station ATTN: WESEN (Dr. V. LaGarde) (Mr. W. Grabau) WESEN-C (Mr. David Meeker) PO Box 631 Vicksburg, MS 39180-0631
1	US Army Engineer Topographic Laboratories ATTN: Technical Director (W. Boge) Fort Belvoir, VA 22060-5546

No. of Copies	Organization
1	Commander US Army Operational Test and Evaluation Agency ATTN: LTC Gordon Crupper 4501 Ford Ave. #870 Alexandria, VA 22302-1435
1	Lawrence Livermore National Laboratory PO Box 808 (L-3321) ATTN: Mark Wilkins Livermore, CA 94551
3	Los Alamos National Laboratory ATTN: MS 985, Dean C. Nelson MS F600, Gary Tietgen MS G787, Terrence Phillips PO Box 1663 Los Alamos, NM 87545
1	Los Alamos National Laboratory ATTN: MS F681, LTC Michael V. Ziehmn USMC PO Box 1668 Los Alamos, NM 87545
1	Sandia National Laboratories Department 913 ATTN: Ron Andreas Albuquerque, NM 87185-5800
1	Sandia National Laboratories Division 1611 ATTN: Tom James Albuquerque, NM 87185
1	Sandia National Laboratories Division 1623 ATTN: Larry Hostetler Albuquerque, NM 87185
1	Sandia National Laboratories ATTN: Gary W. Richter PO Box 969 Livermore, CA 94550

No. of Copies	Organization
1	Commander US Naval Air Systems Command JTCG/AS Central Office ATTN: 5164J (LTC James B. Sebolka) Washington, DC 20361
1	Commander US Naval Ocean Systems Center ATTN: Earle G. Schweizer Code 000 San Diego, CA 92151-5000
4	Commander US Naval Surface Warfare Center ATTN: Gregory J. Budd James Ellis Barbara J. Harris Constance P. Rollins Code G13 Dahlgren, VA 22448-5000
2	Commander US Naval Weapons Center ATTN: Ed Patterson Dr. Helen Wang Code 3313 Bldg 1400, Room B17 China Lake, CA 93555
1	Commander US Naval Weapons Center ATTN: Mark D. Alexander Code 3894 China Lake, CA 93556-6001
1	Commander US Naval Weapons Center ATTN: Melvin H. Keith Code 39104 China Lake, CA 93555
2	Commander US Naval Weapons Center ATTN: Tim Horton Dave Hall Code 3386 China Lake, CA 93555

No. of Copies	Organization
1	Commander US Naval Weapons Center ATTN: Robert Cox Code 3917 China Lake, CA 93555-6001
1	Commander US Naval Civil Eng Laboratories ATTN: John M. Ferritto Code L53 Port Hueneme, CA 93043
1	Naval Postgraduate School ATTN: Dr. Michael J. Zyda Department of Computer Science Code 52 Monterey, CA 93943
1	Naval Postgraduate School Department of National Security ATTN: Dr. Joseph Sternberg Code 73 Monterey, CA 93943
1	Commander Intelligence Threat Analysis Center ATTN: PSD-GAS/John Bickle Washington Navy Yard Washington, DC 20374
1	Commander Intelligence Threat Analysis Center ATTN: Bill Davies Washington Navy Yard, Bldg 203 (Stop 314) Washington, DC 20374-2136
1	Commander Intelligence Threat Analysis Center ATTN: Ron Demeter Washington Navy Yard, B-213, Stop 314 Washington, DC 20374
1	Commander Intelligence Threat Analysis Center ATTN: Tim Finnegan Washington Navy Yard, B-213 Washington, DC 20374

No. of Copies	Organization
2	Commander Intelligence Threat Analysis Center Intell Image Prod Div ATTN: John Creighton Al Fuerst Washington Navy Yard, Bldg 213 (IAX-O-II) Washington, DC 20374
2	Commander David W. Taylor Naval Ship and Development Center ATTN: W. Conley J. Schot Bethesda, MD 20084
1	Commander Eglin Air Force Base AD/ENL ATTN: Robert L. Stovall Eglin AFB, FL 32542
1	Commander USAF HQ ESD/PLEA Chief, Engineering and Test Division ATTN: Paul T. Courtoglous Hanscom AFB, MA 01730
1	Commander USAF-HQ ATTN: AFTDEC/JT (COL Victor A. Kindurys) Kirtland AFB, NM 87117-7001
2	Commander AFATL ATTN: AGA (Lawrence Jones) (Mickie Phipps) Eglin AFB, FL 32542-5434
1	Commander AFEWC ATTN: AFEWC/SAXE (Bod Eddy) Kelly AFB. TX 78243-5000
1	Commander AFWAL/AARA ATTN: Ed Zelano Wright-Patterson AFB, OH 45433

No. of Copies	Organization
1	Commander AFWAL/FIES ATTN: James Hodges Sr. Wright-Patterson AFB, OH 45433-6523
2	Commander AFWAL/MLTC ATTN: LT Robert Carringer Dave Judson Wright-Patterson AFB, OH 45433-6533
1	Commander ASB/XRM ATTN: Gerald Bennett Wright-Patterson AFB, OH
1	Commander WRDC/AARA ATTN: Michael L. Bryant Wright-Patterson AFB, OH 45433
1	Comma der FTD/SLMBA ATTN: Charles Darnell Wright-Patterson AFB, OH 45433
1	Commander FTD/SDMBU ATTN: Kevin Nelson Wright-Patterson AFB, OH 45433
1	Commander FTD/SQDRA ATTN: Greg Koesters Wright-Patterson AFB, OH 45433-6508
1	Commander FTD ATTN: Tom Reinhardt Wright-Patterson AFB, OH 45433
1	Commander FTD/SCRS ATTN: Amy Fox Schalle Wright-Patterson AFB, OH 45433

No. of Copies	Organization
1	Commander FTD/SDJEO ATTN: Robert Schalle Wright-Patterson AFB, OH 45433
1	Commander FTD/SDAEA ATTN: Joe Sugrue Wright-Patterson AFB, OH 45433
1	Commander AFWAL/AARA ATTN: Vincent Velten Wright-Patterson AFB, OH 45433
1	Commander FTD/SQDRA ATTN: Larry E. Wright Wright-Patterson AFB, OH 45433
1	Commander AD/CZL ATTN: James M. Heard Eglin AFB, FL 32542-5000
1	Commander AD/ENY ATTN: Dr. Stewart W. Turner Director of Engineering Analysis Eglin AFB, FL 32542-5000
2	Commander AD/ENYW ATTN: 2LT Michael Ferguson Jim Richardson Eglin AFB, FL 32542-5000
1	Commander Air Force Armament Laboratory ATTN: AFATL/DLY (James B. Flint) Eglin AFB, FL 32542-5000
1	Commander US Army FSTC ATTN: AIAST-RA-SG1 (Dr. Steven Carter) 220 Seventh Avenue Charlottesville, VA 22901-5396

No. of Copies	Organization
4	Commander US Army FSTC ATTN: Greg Crawford David P. Lutz Suzanne Hall Charles Hutson 220 Seventh Avenue Charlosttesville, VA 22901-5396
1	Commander US Army FSTC/CA3 ATTN: Scott Mingledorff 220 Seventh Avenue Charlottesville, VA 22901-5396
1	Commander US Army FSTC (UK) ATTN: MAJ Nigel Williams 220 Seventh Avenue Charlottesville, VA 22901-5396
1	Commander US Army FSTC ATTN: Dr. Tim Small 220 Seventh Avenue Charlottsville, VA 22901-5396
1	Defense Intelligence Agency ATTN: DB-6E3 (Jay Hagler) Washington, DC 20340-6763
6	Institute for Defense Analyses (IDA) ATTN: Mr. Irwin A. Kaufman Mr. Arthur O. Kresse Mr. Arthur Stein Dr. Lowell Tonnessen Mr. Benjamin W. Turner Ms. Sylvia L. Waller 1801 N. Beauregard Street Alexandria, VA 22311
1	Institute for Defense Analyses ATTN: Carl F. Kossack 1005 Athens Way Sun City, FL 33570

No. of Copies	Organization
1	Department of Commerce National Bureau of Standards Manufacturing Systems Group ATTN: B. Smith Washington, DC 20234
1	AAI Corporation ATTN: H. W. Schuette PO Box 126 Hunt Valley, MD 21030-0126
1	ABEX Research Center ATTN: Dr. Michael J. Normandia 65 Valley Road Mahwah, NJ 07430
1	Adelman Associates ATTN: Herbert S. Weintraub 291 North Bernardo Avenue Mountain View, CA 94014-5205
1	The Armed Forces Communications and Electronics Association ATTN: Kirby Lamar, BG(Ret) 4400 Fair Lakes Court Fairfax, VA 22033-3899
2	Aero Corporation ATTN: David S. Eccles Gregg Snyder P.O. Box 92957, M4/913 Los Angeles, CA 90009
1	AFELM, The Rand Corporation ATTN: Library-D 1700 Main Street Santa Monica, CA 90406
2	Air Force Wright Aeronautical Labs ATTN: CDJ, CPT Jost CDJ, Joseph Faison Wright-Patterson AFB, OH 45433-6523
1	Alliant Computer Company ATTN: David Micciche 1 Monarch Drive Littleton, MA 01460

No. of Copies	Organization
1	Alliston Gas Turbine Division of GM ATTN: Michael Swift PO Box 420, SC S22B Indianapolis, IN 46260-0420
1	Aluminum Company of America ATTN: Charles Wood Alcoa Technical Center Alcoa Center, PA 15069
1	ANSER ATTN: James W. McNulty 1215 Jefferson Davis Highway Arlington, VA 22202
1	ARC C-500 ATTN: John H. Bucher Modena Road Coatesville, PA 19320
1	Armament Systems, Inc. ATTN: Gerard Zeller P.O. Box 158 211 West Bel Air Avenue Aberdeen, MD 21001
1	Armored Vehicle Technologies ATTN: Coda M. Edwards PO Box 2057 Warren, MI 48090
1	ASI Sytems, International ATTN: Dr. Michael Stamatelatos 3319 Lone Jack Road Encinitas, CA 92024
1	Auburn University Electrical Engineering Department ATTN: Dr. Thomas Shumpert Auburn University, AL 36849
1	A.W. Bayer and Associates ATTN: Albert W. Bayer, President Marina City Club 4333 Admiralty Way Marina del Rey, CA 90292-5469

No. of Copies	Organization
1	Battelle Research Laboratory Columbus Division 505 King Avenue Columbus, Ohio 43201-2693
1	Battelle Research Laboratory ATTN: Bernard J. Tullington 1300 N. 17th Street, Suite 1520 Arlington, VA 22209
1	The BDM Corporation ATTN: Edwin J. Dorchak 7915 Jones Branch Drive McLean, VA 22102-3396
1	The BDM Corporation ATTN: Fred J. Michel 1300 N. 17th Street Arlington, VA 22209
1	Bell Helicopter, Textron ATTN: Jack R. Johnson PO Box 482 Fort Worth, TX 76101
3	BMY, Division of Harsco ATTN: William J. Wagner, Jr. Ronald W. Jenkins Ed Magalski PO Box 1512 York, PA 17404
1	Board on Army Science and Technology National Research Council Room MH 280 2101 Constitution Avenue, NW Washington, DC 20418
2	Boeing Aerospace ATTN: Dr. Robert Chiavetta Dr. John Kuras Mail Stop 8K17 P.O. Box 3999 Seattle, WA 98124-2499

No. of Copies	Organization
2	Boeing Corporation ATTN: MS 33-04, Robert Bristow MS 48-88, Wayne Hammond PO Box 3707 Seattle, WA 98124-2207
1	Boeing Vertol Company A Division of Boeing Co. ATTN: MS P30-27, John E. Lyons PO Box 16858 Philadelphia, PA 19142
1	Booz-Allen and Hamilton, Inc. ATTN: Dr. Richard B. Benjamin Suite 131, 4141 Colonel Glenn Hwy. Dayton, OH 45431
1	Booz-Allen and Hamilton, Inc. ATTN: Jay A. Lobb 200 E. Big Beaver Rd. Troy, MI 48053
1	Booz-Allen and Hamilton, Inc. ATTN: Lee F. Mallett 1300 N. 17th Street, Suite 1610 Rosslyn, VA 22209
2	Booz-Allen and Hamilton, Inc. ATTN: John M. Vice (2 cys) WRDC/FIVS/SURVIAC Bldg 45, Area B Wright-Patterson AFB, OH 45433-6553
1	John Brown Associates ATTN: Dr. John A. Brown PO Box 145 Berkeley Heights, NJ 07922-0145
1	Chamberlain ATTN: Mark A. Sackett PO Box 2545 Waterloo, IA 50704
1	Commander Combined Arms Combat Development ATTN: ATZL-CAP (LTC Morrison) Dir, Surv Task Force Ft. Leavenworth, KS 66027-5300
1	Commander Combined Arms Combat Development ATTN: ATZL-HFM (Dwain Skelton) Ft. Leavenworth, KS 66027-5300
1	Computer Sciences Corporation 200 Sparkman Drive Huntsville, AL 35805
3	Computervision Corporation ATTN: A. Bhide V. Geisberg R. Hillyard 201 Burlington Road Bedford, MA 01730
1	Cray Research, Inc. ATTN: William W. Kritlow 2130 Main Street, #280 Huntington Beach, CA 92648
1	CRS Sirrine, Inc. ATTN: Dr. James C. Smith PO Box 22427 1177 West Loop South Houston, TX 77227
1	CSC ATTN: Abner W. Lee 200 Sparkman Drive Huntsville, AL 35805
2	Cypress International ATTN: August J. Caponecchi James Logan 1201 E. Abinjdon Drive Alexandria, VA 22314
1	DATA Networks, Inc. ATTN: William E. Regan, Jr. President 288 Greenspring Station Brooklandville, MD 21022
1	Datatec, Inc. ATTN: Donald E. Cudney President 326 Green Acres Fort Walton, FL 32548

No. of Copies	Organization
1	University of Dayton Graduate Engineering and Research Kettering Lab 262 ATTN: Dr. Gary Thiele, Director Dayton, OH 45469
1	Delco Systems Operation ATTN: John Steen 6767 Hollister Avenue, #P202 Goleta, CA 93117
1	Denver Research Institute Target Vulnerability and Survivability Laboratory ATTN: Lawrence G. Ullyatt PO Box 10127 Denver, CO 80210
1	Denver Research Institute University of Denver ATTN: Louis E. Smith University Park Denver, CO 80208
1	Dow Chemical, U.S.A ATTN: Dr. P. Richard Stoesser Contract R&D 1801 Building Midland, MI 48674-1801
1	Drexel University ATTN: Dr. Pei Chi Chou College of Engineering Philadelphia, PA 19104
1	DuPont Company FPD ATTN: Dr. Oswald R. Bergmann B-1246, 1007 Market Street Wilmington, DE 19898
1	Dynamics Analysis and Test Associates ATTN: Dr. C. Thomas Savell 2231 Faraday Ave Suite 103 Carlsbad, CA 92008
1	E. I. Dupont TED FMC ATTN: Richard O. Myers Jr. Wilmington, DE 19898

No. of Copies	Organization
1	Eichelberger Consulting Company ATTN: Dr. Robert Eichelberger President 409 West Catherine Street Bel Air, MD 21014
1	Electronic Warfare Associates, Inc. ATTN: William V. Chiaramonte 2071 Chain Bridge Road Vienna, VA 22180
1	Emprise, Ltd. ATTN: Bradshaw Armendt, Jr 201 Crafton Road Bel Air, MD 21014
8	Environmental Research Institute of Michigan ATTN: Mr. K. Augustyn Mr. Kozma Dr. I. La Haie Mr. R. Horvath Mr. Arnold Mr. E. Cobb Mr. B. Morey Mr. M. Bair PO Box 8618 Ann Arbor, MI 48107
1	E-OIR Measurements, Inc. ATTN: Russ Moulton PO Box 3348, College Station Fredericksburg, VA 22402
1	ERIM ATTN: Stephen R. Stewart Exploitation Applications Department Image Processing Systems Division PO Box 8618 Ann Arbor, MI 48107-8618
1	USA ETL/IAG ATTN: Jim Campbell Bldg 2592, Room S16 Ft. Belvoir, VA 22060-5546
1	FMC Corporation ATTN: Sidney Kraus 1105 Coleman Ave, Box 1201 San Jose, CA 95108

No. of Copies	Organization
3	FMC Corporation ATTN: Ronald S. Beck Martin Lim Jacob F. Yacoub 881 Martin Avenue Santa Clara, CA 95052
3	FMC Corporation Advanced Systems Center (ASC) ATTN: Edward Berry Scott L. Langlie Herb Theumer 1300 South Second Street PO Box 59043 Minneapolis, MN 55459
2	FMC Corporation Defense Systems Group ATTN: Robert Burt Dennis R. Nitschke 1115 Coleman Avenue San Jose, CA 95037
1	FMC Corporation Naval Systems Division (NSD) ATTN: MK-45, Randall Ellis Minneapolis, MN 55421
1	FMC Corporation Northern Ordnance Division ATTN: M3-11, Barry Brown 4800 East River Road Minneapolis, MN 55421
6	FMC Corporation Ordnance Engineering Division ATTN: H. Croft M. Hatcher L. House J. Jackson E. Maddox R. Musante 1105 Coleman Ave, Box 1201 San Jose, CA 95108
1	GE Aircraft Engines ATTN: Dr. Roger B. Dunn One Neumann Way, MD J185 Cincinnati, OH 45215-6301

No. of Copies	Organization
1	General Atomics ATTN: Chester J. Everline, Staff Engineer P.O. Box 85608 San Diego, CA 92138-5608
1	General Dynamics ATTN: Dr. Fred Cleveland P.O. Box 748 Mail Zone 5965 Ft. Worth, TX 76101
3	General Dynamics ATTN: MZ-4362112, Robert Carter MZ-4362029, Jim Graciano MZ-4362055, Gary Jackman 38500 Mound Sterling Heights, MI 48310
3	General Dynamics Corporation ATTN: MZ-2650, Dave Bergman MZ-2860, John Romanko MZ-2844, Cynthia Waters PO Box 748 Ft. Worth, TX 76101-0748
1	General Dynamics Land Systems ATTN: Robert Carter PO Box 1804 Warren, MI 48090
1	General Dynamics Land Systems ATTN: Dr. Paulus Kersten PO Box 1901 Warren, MI 48090
1	General Dynamics Land Systems ATTN: William M. Mrdeza PO Box 2045 Warren, MI 48090
5	General Dynamics Land Systems ATTN: Richard Auyer Otto Renius N. S. Sridharan Dean R. Loftin Dr. Phil Lett PO Box 2074 Warren, MI 48090-2074

No. of Copies	Organization
3	General Motors Corporation Research Laboratories ATTN: J. Boyse J. Joyce R. Sarraga Warren, MI 48090
1	General Motors Corporation Military Vehicles Operations Combat Vehicle Center ATTN: Dr. John A. MacBain PO Box 420 Mail Code 01 Indianapolis, IN 46206-0420
1	Gettysburg College Box 405 Gettysburg, PA 17325
1	Grumman Aerospace Corporation Research and Development Center ATTN: Dr. Robert T. Brown, Senior Research Scientist Bethpage, NY 11714
1	GTRI-RAIL-MAD ATTN: Mr. Joe Bradley CRB 577 Atlanta, GA 30332
1	Honeywell ATTN: Hatem Nasr Systems and Research Center 3660 Technology Drive PO Box 1361 Minneapolis, MN 55418
1	Honeywell ATTN: Fred J. Parduhn 7225 Northland Drive Brooklyn Park, MN 55428
2	Honeywell, Inc. ATTN: Raymond H. Burg Laura C. Dillway MN38-4000 10400 Yellow Circle Drive Minnetonka, MN 55343

No. of Copies	Organization
2	INEL/EG&G Engineer Lab ATTN: Ray Berry M. Marx Hintze PO Box 1625 Idaho Falls, ID 83451
1	Interactive Computer Graphics Center Rensselear Polytechnic Inst. ATTN: M. Wozny Troy, NY 12181
1	International Development Corporation ATTN: Trevor C. Jones 18400 Shelburne Road Shaker Heights, OH 44118
1	ISAT ATTN: Roderick Briggs 1305 Duke Street Alexandria, VA 22314
1	Jet Propulsion Laboratory California Institute of Technology ATTN: D. Lewis 4800 Oak Grove Drive Pasadena, CA 91109
1	Kaman Sciences Corporation ATTN: Timothy S. Pendergrass 600 Boulevard South, Suite 208 Huntsville, AL 35802
1	Ketron, Inc. ATTN: Robert S. Bennett 696 Fairmont Avenue Towsontown Center Towson, MD 21204
1	Keweenaw Research Center Michigan Technological University ATTN: Bill Reynolds Houghton, MI 49931
1	Lanxido Armor Products ATTN: Dr. Robert A. Wolffe Tralee Industrial Park Newark, DE 19711

No. of Copies	Organization
2	Lincoln Laboratory MIT ATTN: Dr. Robert Shin Dr. Chuck Burt P.O. Box 73 Lexington, MA 02173
3	Lincoln Laboratory MIT Surveillance Systems Group ATTN: R. Barnes G. Knittel J. Kong 244 Wood Street Lexington, MA 02173-0073
1	Lockheed Corporation ATTN: R. C. Smith PO Box 551 Burbank, CA 91520
3	Lockheed-California Company ATTN: C. A. Burton R. J. Ricci M. Steinberg Burbank, CA 91520
2	Lockheed-Georgia Company ATTN: Ottis F. Teuton J. Tulkoff Dept. 72-91, Zone 419 Marietta, GA 30063
1	Logistics Management Institute ATTN: Edward D. Simms Jr. 6400 Goldsboro Road Bethesda, MD 20817-5886
1	Los Alamos Technical Associates, Inc. ATTN: John S. Daly 6501 Americas Parkway, #900 Albuquerque, NM 87110
1	LTV ATTN: MS 194-51, Mike Logan PO Box 225907 Dallas, TX 75265

No. of Copies	Organization
1	LTV Aerospace and Defense ATTN: Daniel M. Reedy PO Box 225907 Dallas, TX 75265
3	Martin Marietta Aerospace ATTN: MP-113, Dan Dorfman MP-433, Richard S. Dowd MP-243, Thomas C. D'Isepo PO Box 555837 Orlando, FL 32855-5837
3	Mathematical Applications Group, Inc. ATTN: M. Cohen R. Goldstein H. Steinberg 3 Westchester Plaza Elmsford, NY 10523
1	Maxwell Laboratories, Inc. ATTN: Dr. Michael Holland 8888 Balboa Avenue San Diego, CA 92123-1506
1	McDonald-Douglas Astronautic ATTN: Nikolai A. Louie 5301 Bolsa Avenue Huntington Beach, CA 92647
1	McDonnell Douglas, Inc. ATTN: David Hamilton PO Box 516 St. Louis, MO 63166
1	McDonnell Douglas, Inc. ATTN: Alan R. Parker 3855 Lakewood Blvd., MC 35-18 Long Beach, CA 90846
1	Memex Corporation ATTN: Charles S. Smith 91 Belleau Ave. Atherton, CA 94025
1	Micro Electronics of North Carolina ATTN: Gershon Kedem PO Box 12889 Research Triangle Park, NC 07709

No. of Copies	Organization
1	MIT ATTN: Dr. S. Benton RE15-416 Cambridge, MA 02139
5	The MITRE Corporation ATTN: Edward C. Brady, Vice President Dr. Nicklas Gramenopoulos Gordon J. MacDonald Dr. Narayana Srinivasan Norman W. Huddy 7525 Colshire Drive McLean, VA 22102-3184
1	NASA-Ames Research Center ATTN: Dr. Alex Woo Mail Stop 227-2 Moffett Field, CA 94035
1	NASA-Ames Research Center ATTN: Leroy Presley Mail stop 227-4 Moffett Field, CA 94035
1	NAVIR DEVCON ATTN: Frank Wenograd Code 6043 Warminster, PA 18974
1	North Aircraft ATTN: Dr. Athanosis Varvatsis Mail Zone 3622/84 1 Northrop Ave Hawthorne, CA 90250
1	Northrop Corporation Research and Technology Center ATTN: James R. Reis One Research Park Palos Verdes Peninsula, CA 90274
1	Norton Company ATTN: Ronald K. Bart 1 New Bond Street Worcester, MA 01606-2698

No. of Copies	Organization
1	The Oceanus Company ATTN: RADM Robert H. Gormley, (Ret) PO Box 7069 Menlo Park, CA 94026
1	Oklahoma State University College of Engineering, Architecture and Technology ATTN: Thomas M. Browder, Jr. PO Box 1925 Eglin AFB, FL 32542
1	Pacific Scientific/Htl Division ATTN: Robert F. Aldrich 1800 Highland Avenue Duarte, CA 91010
1	Perceptronics, Inc. ATTN: Dean R. Loftin 21111 Erwin Street Woodland Hills, CA 91367
1	Princeton University Mathematics Department Fine Hall Washington Road ATTN: John Tukey Princeton, NJ 08544-1000
1	PRI, Inc. ATTN: W. Bushell Building E4435, Second Floor Edgewood Area-APG, MD 21010
1	RGB Associates, Inc. ATTN: R. Barakat Box B Wayland, MA 01778
1	Rockwell International ATTN: Dr. H. Bran Tran P.O. Box 92098 Department 113/GB01 Los Angeles, CA 90009

No. of Copies	Organization
1	Rockwell International Corporation ATTN: Keith R. Rathjen, Vice President 3370 Miraloma Avenue (031-HA01) Anaheim, CA 92803-3105
1	Rome Air Development Center ATTN: RADC/IRRE, Peter J. Costianes Griffis Air Force Base, NY 13441-5700
1	Rome Air Development Center RADC/OCTM ATTN: Edward Starczewski Building 106 Griffis Air Force Base, NY 13441-5700
1	S-Cubed ATTN: Michael S. Lancaster 1800 Diagonal Road, Suite 420 Alexandria, VA 22314
1	Sachs/Freeman Associates, Inc. ATTN: Donald W. Lynch Senior Research Physicist 205 Yoakum Parkway, #511 Alexandria, VA 22304
1	SAIC ATTN: Dr. Alan J. Toepfer 2109 Air Park Drive, SE Albuquerque, NM 87106
1	SAIC ATTN: John H. McNeilly, Senior Scientist 1710 Goodridge Drive McLean, VA 22102
2	SAIC ATTN: Terry Keller Robert Turner Suite 200 1010 Woodman Drive Dayton, OH 45432

No. of Copies	Organization
1	SAIC ATTN: David R. Garfinkle Malibu Canyon Business Park 26679 W. Agoura Road, Suite 200 Calabasas, CA 91302
1	Sidwell-Ross and Associates, Inc. ATTN: LTG Marion C. Ross, (USA Ret) Executive Vice President PO Box 88531 Atlanta, GA 30338
1	Sigma Research Inc. ATTN: Dr. Richard Bossi 4014 Hampton Way Kent, WA 98032
1	Simula, Inc. ATTN: Joseph W. Coltman 10016 South 51st Street Pheonix, AZ 85044
1	SimTech ATTN: Dr. Annie V. Saylor 3307 Bob Wallace Ave., Suite 4 Huntsville, AL 35807
1	Alan Smolen and Associates, Inc. ATTN: Alan Smolen, President One Cynthia Court Palm Coast, FL 32027-8172
3	Southwest Research Institute ATTN: Martin Goland Alex B. Wenzel Patrick H. Zabel 6220 Culebra Road San Antonio, TX 78238
3	Sparta, Inc. ATTN: David M. McKinley Robert E. O'Connor Karen M. Rooney 4901 Corporate Drive Huntsville, AL 35805-6201

No. of Copies	Organization
1	SRI International ATTN: Donald R. Curran 333 Ravenswood Ave. Menlo Park, CA 94025
2	Star Laboratory, Stanford University ATTN: Dr. John F. Vesecky Dr. Joseph W. Goodman Electrical Engineering Department 233 Durand Building Stanford, CA 94305-4055
3	Structural Dynamics Research Corporation (SDRC) ATTN: R. Ard W. McClelland J. Osborn 2000 Eastman Drive Milford, OH 45150
1	Syracuse Research Group ATTN: Dr. Chung-Chi Cha Merrill Lane Syracuse, NY 13210
1	System Planning Corporation ATTN: Ann Hafer 1500 Wilson Blvd Arlington, VA 22209
1	S-Cubed ATTN: Robert T. Sedgwick PO Box 1620 La Jolla, CA 92038-1620
2	TASC ATTN: Charles E. Clucus Darrell James 970 Mar-Walt Drive Ft. Walton Beach, FL 32548
1	TASC ATTN: Harry I. Nimon, Jr 1700 N. Moor. Street, Suite 1220 Arlington, VA 22209

No. of Copies	Organization
1	Technical Solutions, Inc ATTN: John R. Robbins P.O. Box 1148 Mesillia Park, NM 88047
1	Teledyne Brown Engineering ATTN: John W. Wolfsberger, Jr. Cummings Research Park 300 Sparkman Drive, NW PO Box 070007 Huntsville, AL 35807-7007
1	Tradeways, Ltd. ATTN: Joseph G. Gorski, President 307F Maple Avenue West Vienna, VA 22180
1	Ult.amet ATTN: Dr. Jacob J. Stiglich 12173 Montague Street Pacoima, CA 91331
1	United Technologies Corporation Advanced Systems Division ATTN: Richard J. Holman 10180 Telesis Court San Diego, CA 92121
1	University of Idaho Department of Civil Engineering ATTN: Dr. Dennis R. Horn Assistant Professor Moscow, ID 83843-4194
1	University of Illinois at Chicago Communications Laboratory ATTN: Dr. Wolfgang-M. Boerner PO Box 4348 M/C 154, 1141-SEO Chicago, IL 60680
1	University of Illinois at Urbana-Champaign Department of Civil Engineering and Environmental Studies ATTN: Dr. E. Downey Brill, Jr. 208 North Romine Urbana, IL 61801-2374

No. of Copies	Organization
1	University of Illinois Department of Electrical and Computer Engineering ATTN: Dr. Shung-Wu Lee 1406 W. Green Urbana, IL 61801
1	The Johns Hopkins University Applied Physics Laboratory ATTN: Jonathan Fluss Johns Hopkins Road Laurel, MD 20707
1	University of Nevada Environmental Research Center ATTN: Dr. Delbert S. Barth Senior Scientist Las Vegas, NV 89154-0001
1	University of North Carolina ATTN: Professor Henry Fuchs 208 New West Hall (035A) Chapel Hill, NC 27514
3	Ohio State University Electroscience Laboratory ATTN: Dr. Ronald Marhefka Dr. Edward H. Newman Dr. Prasbhaker H. Pathak 1320 Kinnear Road Columbus, OH 43212
1	University of Rochester ATTN: Nicholas George College of Engineering and Applied Science Rochester, NY 14627
3	University of Utah Computer Science Department ATTN: R. Riesenfeld E. Cohen L. Knapp 3160 Merrill Engineering Bldg Salt Lake City, UT 84112

No. of Copies	Organization
3	University of Washington 409 Department of Electrical Engineering, FT-10 ATTN: Dr. Irene Peden Dr. Akira Ishimaru Dr. Chi Ho Chan Seattle, WA 98105
1	Van Es Associates, Inc. ATTN: Dr. John D. Christie Vice President Suite 1407, 5202 Leesburg Pike Falls Church, VA 22041
1	Virginia Polytechnic Institute and State University Industrial Engineering Operations Research Department ATTN: Robert C. Williges 302 Whittemore Hall Blacksburg, VA 24061-8603
1	LTV Aircraft Products Group ATTN: Paul T. Chan, m/s194-63 PO Box 655907 Dallas, TX 75265-5907
1	XMCO, Inc. 460 Spring Park Pl #1500 Herndon, VA 22070-5215
1	XONTECH ATTN: John Dagostino 1701 N. Fort Myer Drive Suite 703 Arlington, VA 22209
1	Zernow Tech Services, Inc. ATTN: Dr. Louis Zernow 425 West Bonita, Suite 208 San Dimas, CA 91773
2	SURVICE Engineering ATTN: Jim Foulk George Lard 1003 Old Philadelphia Road Aberdeen, MD 21001

No. of Copies	Organization
1	SURVICE Engineering ATTN: Edwin S. Wixson 3200 Carlisle Blvd., NE Suite 120 Albuquerque, NM 87100
2	Sverdrup Technology ATTN: Dr. Ralph Calhoun Bud Bruenning PO Box 1935 Eglin AFB, FL 32542
1	Georgia Technical Research Institute Systems and Technical Laboratory ATTN: Dr. Charles Watt 1770 Richardsons Road Smyrna, GA 30080
1	Georgia Institute of Technology ATTN: Dr. Richard Moore ECSL/EME ERB Building, Room 111 Atlanta, GA 30332
1	Duke University Department of Computer Science, VLSI Raycasting ATTN: Dr. Gershon Kedem 236 North Building Durham, NC 27706
1	Virginia Technological Institute Electrical Engineering Department ATTN: Dr. David de Wolf 340 Whittemore Hall Blacksburg, VA 24061

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: AMXSY-A, W. Clifford
J. Meredith
AMXSY-C, A. Reid
W. Braerman
AMXSY-CR, M. Miller
AMXSY-CS, P. Beavers
C. Cairns
D. Frederick
AMXSY-G, J. Kramar
G. Comstock
E. Christman
L. Kravitz
AMXSY-GA, W. Brooks
AMXSY-J, A. LaGrange
AMXSY-L, J. McCarthy
AMXSY-P, J. Cullum
AMXSY-RA, R. Scungio
M. Smith

Cdr, USATECOM
ATTN: AMSTE-CG, MG Akin
AMSTE-LFT, D. Gross
R. Harrington
AMSTE-CG-LF
AMSTE-TC-C, R. Cozby

Dir, USAVLAMO
ATTN: AMSLC-VL-D, Gary Holloway
ATTN: AMSLC-VL-CB, Mrs. Young
Mr. Gross

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number BRL-TR-3161 Date of Report OCTOBER 1990

2. Date Report Received ____________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ____________

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ____________

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ____________

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ____________

CURRENT ADDRESS

Name

Organization

Address

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name

Organization

Address

City, State, Zip Code

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)

---FOLD HERE---

DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 2100·'-5066

OFFICIAL BUSINESS

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS PERMIT No 0001, APG, MD

POSTAGE WILL BE PAID BY ADDRESSEE

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-9989

---FOLD HERE---